State of Connecticut

State Geological and History Survey

BULLETIN No. 6

MANUAL

OF THE

GEOLOGY OF CONNECTICUT

By

WILLIAM NORTH RICE, Ph.D., LL.D.
Professor of Geology in Wesleyan University

AND

HERBERT ERNEST GREGORY, Ph.D.
Professor of Geology in Yale University

State of Connecticut

PUBLIC DOCUMENT No. 47

State Geological and Natural History Survey

COMMISSIONERS

HENRY ROBERTS, Governor of Connecticut (*Chairman*)
ARTHUR TWINING HADLEY, President of Yale University
BRADFORD PAUL RAYMOND, President of Wesleyan University
FLAVEL SWEETEN LUTHER, President of Trinity College (*Secretary*)
RUFUS WHITTAKER STIMSON, President of Connecticut Agricultural College

SUPERINTENDENT
WILLIAM NORTH RICE

BULLETIN No. 6

HARTFORD PRESS
The Case, Lockwood & Brainard Company
1906

MANUAL

OF

THE GEOLOGY OF CONNECTICUT

By

WILLIAM NORTH RICE, Ph.D., LL.D.,

Professor of Geology in Wesleyan University

AND

HERBERT ERNEST GREGORY, Ph.D.,

Professor of Geology in Yale University

Hartford Press

The Case, Lockwood & Brainard Company

1906

Preface.

In the present Bulletin we propose to give, in form and language no more technical than is necessary, an outline of what is known in regard to the geological structure and history of Connecticut.

It is believed that such a work will be useful to various classes of readers. Students of geology in other regions will find here a brief statement of the characteristic features of a small but interesting area. Intelligent citizens of our own State will learn somewhat of the character of the rock formations upon whose surface they live, and of the agencies by which in the course of ages the surface has been molded to its present form and condition. Especially, however, this Bulletin is designed for the use of teachers of science within our own state; and in its preparation we have had particularly in mind that educational aim which is wisely emphasized in the law by which the State Survey was established. From teachers, particularly in the high schools of the state, the question has repeatedly come to us, where can a clear and intelligible account of Connecticut geology be found? To that question no satisfactory answer could be given. While much work has been done in the investigation of Connecticut geology, by private individuals and by officers of the State and National Surveys, the results of that investigation have never been put together in any accessible form. They may be found in part scattered through many volumes of scientific journals and official reports. Much of the older work was published at a time when the language, as well as the thought, of geologists was so different from that of the present time that the writings are not easily intelligible to elementary students at the present day. Many of our teachers do not have access to large libraries, and comparatively few have learned the art of collecting the information which they desire from fragmentary

articles scattered through many volumes. Much of the most recent work on the geology of Connecticut still remains unpublished. It is believed, therefore, that in the work of the teachers of the state this Bulletin will meet a long-felt want.

To geologists it is unnecessary to say, but to the general reader it is important to say emphatically, that this Bulletin does not aim to set forth a complete and final statement of the geology of Connecticut. In spite of all the earnest study that has been given to this field, there are many questions still unanswered; and the knowledge which we possess seems small in comparison with the territory of the unknown. The problems presented by the Triassic are simpler than those presented by the crystalline rocks, and have been much more nearly solved; but, even in regard to the Triassic, important questions still remain without any answer conclusively established or unanimously accepted. Over how wide an area the Triassic sediments extended before the great denudation, and to what extent the western border was formed by faults, are questions in regard to which there is room for difference of opinion. In regard to the dynamics of the tilting and faulting of the Triassic area, any explanation that can be given is only a matter of speculation. In the crystalline rocks the ratio of our knowledge to our ignorance is far smaller than in the Triassic. How much of the crystalline rocks is igneous, and how much is sedimentary in origin; to what extent the foliation represents stratification; what are the stratigraphical relations of the different crystalline formations; in what periods the crystalline rocks of sedimentary origin were deposited, and in what periods they were disturbed and metamorphosed; how many different epochs of disturbance and metamorphism have left their traces upon some of the rocks; all these are questions to which only partial and uncertain answers can be given. Obviously, then, the present paper is in large degree provisional. It is a report of progress; not a final report. It may be hoped that future investigation will correct some of its errors and answer some of its

questions; but, however many interrogation points may be changed to periods in the progress of knowledge, it seems not unlikely that for generations to come the new questions which will be started may be more numerous than the old questions which will be answered. The problem of our crystalline rocks seems, in the present state of our knowledge, to be analogous to mathematical problems in which the number of unknown quantities exceeds the number of equations. In the treatment of all these subjects, we have endeavored to avoid the spirit or the appearance of dogmatism; and have frankly confessed the uncertainty which we feel. We hope, therefore, that from these pages the attentive reader will learn but little that he will have to unlearn in the progress of science.

The two authors whose names appear on the title-page of this Bulletin have freely consulted with each other, and have accepted suggestions from each other in the preparation of their respective parts of the work. In the main the two authors are substantially in agreement in their geological views. It is to be understood, nevertheless, that each is to be held solely responsible for the chapters which bear his name.

The first chapter of the present work is a re-publication, with additions and alterations, of an address before the State Board of Agriculture, published in their Report for 1903. Acknowledgments are due to the officers of the United States Geological Survey for permission liberally accorded to use in the preparation of this Bulletin the unpublished results of the work of the Survey. Acknowledgments are particularly due to Professor W. H. Hobbs, of the University of Wisconsin, who has placed at our disposal the results of his detailed and thorough study of the western part of Connecticut. The contributions of Professor L. G. Westgate, of Ohio Wesleyan University, Dr. H. H. Robinson, of Yale University, and Dr. G. F. Loughlin, of the Massachusetts Institute of Technology, to the study of particular areas of the state, are appropriately acknowledged in the sections of the work relating to those areas. A number

of illustrations are from photographs taken for the United States Geological Survey, under the direction of Professor W. M. Davis, of Harvard University, by whose courtesy they were placed at our disposal. Acknowledgments are also due to Professor Westgate, Dr. Robinson, Mr. Freeman Ward, Professor G. P. Merrill, of the United States National Museum, Mr. Sidney M. Loyd, of Lynchburg, Va., and others, for the use of photographs. Two figures of reptilian tracks on the Triassic sandstones, from Lull's *Fossil Footprints of the Jura-Trias,* are used by permission of author and publisher, the electrotypes being lent to us by the Boston Society of Natural History.

It might have been appropriate to present in this Bulletin a general historical sketch of the work of National and State Surveys and of private individuals in Connecticut. For that information, however, the reader is referred to the pamphlet accompanying the colored Geological Map of Connecticut, published as Bulletin No. 7.

William North Rice,
Herbert Ernest Gregory.

CONTENTS.

CONTENTS.

ILLUSTRATIONS

Chapter I

The Geography of Connecticut

As Related to Geological Structure and History

By

WILLIAM NORTH RICE

THE GEOGRAPHY OF CONNECTICUT.

Geographical Divisions. — The State of Connecticut is naturally divided into three areas, which may be called, respectively, the Eastern Highland, the Western Highland, and the Central Lowland.* The Central Lowland may be further divided into a central range of hills and an eastern and a western valley. The eastern valley may not improperly be called the Connecticut Valley, since the Connecticut River flows in this valley from the gorge between Mount Tom and Mount Holyoke in Massachusetts as far south as Middletown.† At Middletown, however, the Connecticut River leaves the Lowland, and flows to the Sound at Saybrook, through a narrow gorge excavated in the corner of the Eastern Highland. The western valley may be conveniently called the Farmington-Quinnipiac Valley. We shall see hereafter that this valley was once occupied by a continuous river, portions of whose course are included in the present Farmington and Quinnipiac.‡ The central hill range extends across the state in an approximately north and south direction, though broken into fragments arranged in parallel and overlapping lines. Parts of the Lowland are traversed by minor hill ranges approximately parallel to the main central range. The accompanying geological map (Fig. 1) shows well these geographical divisions, since the areas of crystalline rocks correspond substantially with the Eastern and Western Highlands, and the large area of Tri-

* The western boundary of the Central Lowland may be traced through the towns of Granby, Canton, Avon, Farmington, Burlington, Bristol, Southington, Cheshire, Prospect, Bethany, Woodbridge, New Haven, and Orange. Its eastern boundary may be traced through the towns of Somers, Ellington, Vernon, Manchester, Glastonbury, Portland, Middletown, Durham, Guilford, North Branford, Branford, and East Haven.

† The whole Central Lowland is often called the Connecticut Valley, especially when the whole of Southern New England, rather than Connecticut alone, is under discussion.

‡ See pages 221 and 253.

assic rocks with the Central Lowland, while the linear areas of the trap rocks mark the position of the hill ranges in the Lowland.

Connecticut is, of course, not isolated in its physical geography from the adjacent states. The Central Lowland extends northward, as a well marked region, nearly to the northern boundary of Massachusetts, and is traversed by the Connecticut River in its course across the state. Farther north the Eastern and Western Highlands coalesce into the great highland region of northern New England and southeastern Canada, bounded by the Hudson-Champlain Valley, the St. Lawrence Valley, and the Atlantic. The Connecticut River flows between Vermont and New Hampshire in a narrow valley contrasting strongly with the broad Central Lowland of Massachusetts and Connecticut. The Highland region in Vermont and New Hampshire attains a greater mean altitude and is dominated by far loftier summits than in Connecticut.

In the edition of the topographical map of Connecticut, which has been published with the forest areas colored green, the distinction of these three districts of the state is very conspicuous. The Eastern and the Western Highland, with the exception of strips along the sea coast, are largely covered by forests, while in the Central Lowland there are no forest areas of any consequence, excepting on the hill ranges already mentioned. The thin, rocky soil of the Highlands is comparatively unattractive for the agriculturist, and large areas have, therefore, been left covered with forests. In recent time, indeed, the area of cultivation in the Highlands has diminished, and the forest has encroached upon the abandoned farms. The deep and fertile soil of the Lowland led to the early settlement of that strip of country, and a large part of the territory was early brought under cultivation. The old towns of Windsor, Hartford, Wethersfield, Middletown, and New Haven are all distributed along the Central Lowland.

The surface of the Highlands is exceedingly rugged, showing very little indeed of level ground. It is, however,

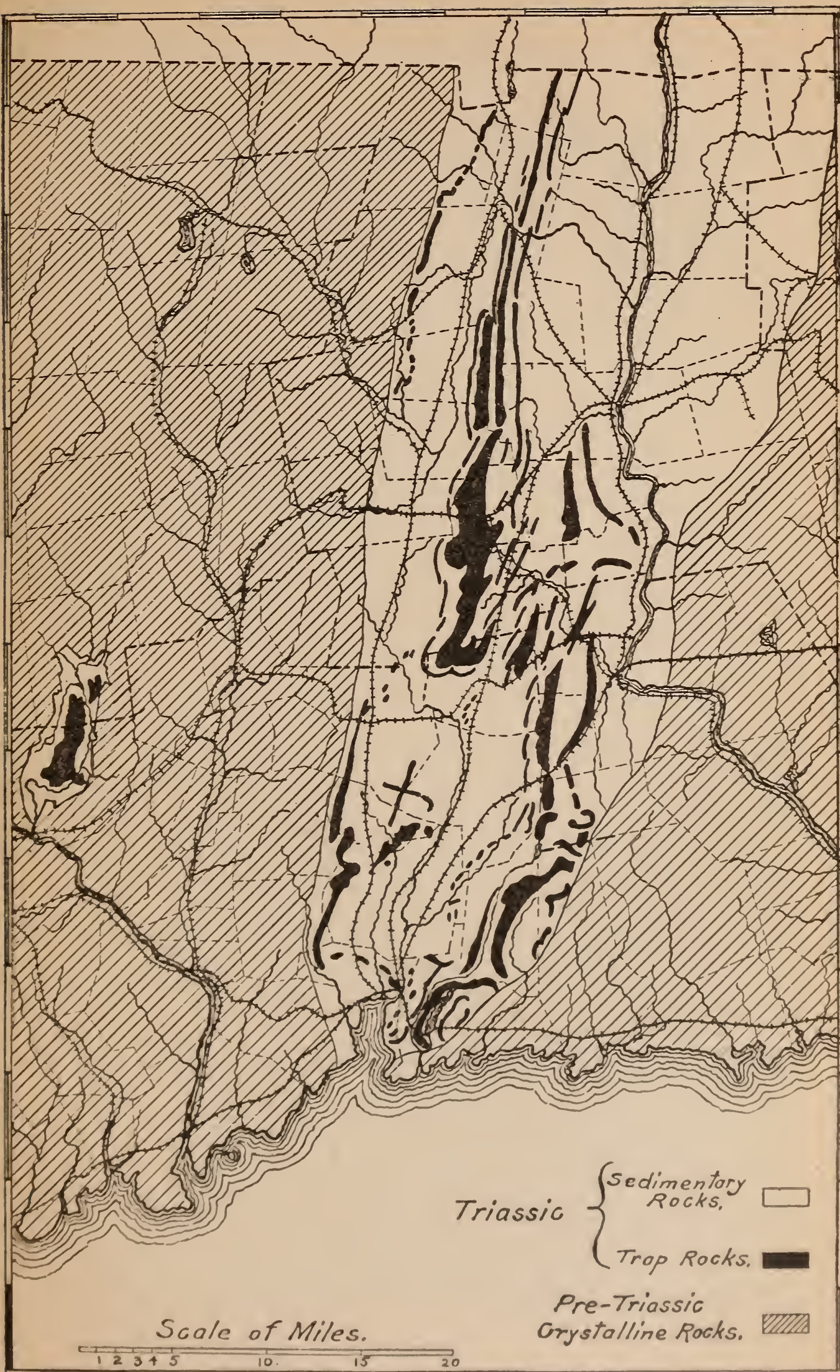


Fig. 1. GEOLOGICAL MAP OF CENTRAL CONNECTICUT.
The large area of Triassic is the Central Lowland; the areas of crystalline rocks are the Highlands.

a remarkable fact that, in almost any general view of either of these highland areas, the sky line appears remarkably straight and nearly level. This appearance is very strikingly shown when the observer stands on West Peak of the Hanging Hills at Meriden,* or on any other high summit of the hill ranges within the Lowland. If we should imagine a sheet of pasteboard resting upon the summits of the highest elevations of Litchfield County and sloping southeastward in an inclined plane, that imaginary sheet of pasteboard would rest on nearly all the summits of both the Eastern and the Western Highlands. This condition obviously suggests the hypothesis that the Eastern and Western Highlands were at one time nearly level plateaus, which have acquired their present rugged surface by the excavation of innumerable valleys. It should be noted also that the hill ranges in the Central Lowland rise to such an altitude that their highest summits do not differ greatly in elevation from the parts of the Highland areas lying to the east and west. Our imaginary sheet of pasteboard, resting on the summits of the rugged Highlands, would touch also many of the culminating points of the hill ranges in the Lowland. These hill ranges present a remarkable uniformity in shape and aspect. They have, in general, as shown in Plate II, a steep face on the west and a gentle slope on the east.

We must now endeavor to correlate these topographical facts with the geological structure of the respective areas; for, as the body without the spirit is dead, so geography without geology is dead also.

Geological Structure of Highlands and Lowland.— If we examine the rocks of the Highlands and the Lowland, respectively, we shall find characteristic differences in many respects. The Lowland rocks are very obviously composed of grains which are rounded more or less perfectly as if water-worn, and which have evidently been derived from the disintegration of earlier rocks. These rounded grains are stuck together by cementing material, composed largely of

* See Plate I.

PLATE I.

VIEW FROM WEST PEAK, MERIDEN, SOUTHWESTWARD ACROSS CENTRAL LOWLAND TO MOUNT CARMEL AND EDGE OF WESTERN HIGHLAND.

Photograph taken under direction of W. M. Davis, for U. S. Geological Survey.

PLATE II.

LAMENTATION MOUNTAIN AND CHAUNCEY PEAK.

Lamentation Mountain is seen at the left nearly in profile; the west face of Chauncey Peak is seen at the right.
Photograph by L. G. Westgate.

PLATE III.

FIG. 1.

FIG. 2.

FIG. 1. Microscopic Section of Sandstone, Portland.
FIG. 2. Microscopic Section of Gneiss, Middletown.

From Report on Building Stones, by Hawes, Merrill, and others, Tenth Census of U. S.

PLATE IV.

SANDSTONE QUARRY, PORTLAND.

Photograph by L. G. Westgate.

red oxide of iron, which fills the chinks between the different grains. In some of the rocks the water-worn fragments are bowlders several inches in diameter; in others, the sandstones proper, the grains are finer, but still large enough to be easily recognized with the naked eye or with a hand lens. In some of the shales the grains are so fine as not to be easily seen without a microscope. When thin sections of these rocks are examined under the microscope, the grains of sand, consisting largely of quartz, but in part of feldspar and other minerals, seem to be translucent, while the cement which fills the chinks between them is nearly opaque. Totally different in character are the rocks of the Highlands. They show no indication of being composed of broken or worn fragments of preexistent rock. They consist of crystalline grains nicely dovetailed together and evidently formed in their present relation to each other. The contrast between the two types of rock, as seen under the microscope, is well shown in Plate III. In technical language, the Lowland rocks are fragmental, the Highland rocks are crystalline.

If, instead of looking in detail at the texture of the rocks of these respective regions, we look at the structures which they show in the mass, we find that the Lowland rocks are arranged in parallel beds or strata, which are sometimes, as in the great quarries of Portland,* almost perfectly horizontal, but which, in most localities, show a moderate dip towards the east or southeast. In the Highland rocks we find sometimes parallel divisional surfaces, giving them an appearance of stratification. In those of the Highland rocks which are thus apparently stratified, the apparent strata are generally tilted up so as to dip at a high angle, and they are often folded and even extremely contorted. In many localities in the Highlands the rocks show no traces of stratification whatever.

These facts of texture and structure show that the Lowland rocks are sediments deposited from water. The Highland rocks are in part rocks which were once deposited as sediments, but which have been so greatly altered by the

* See Plate IV.

action of subterranean heat and pressure and the chemical action of percolating waters and vapors, as to lose entirely their former character of sedimentary rocks. Other parts of the rocks of the Highlands were formed as igneous rocks by solidification from a state of fusion. These igneous rocks, as well as the sedimentary rocks, have for the most part suffered great alteration by subterranean processes, mechanical and chemical. To what has been said in regard to the Lowland rocks, the trap rocks, which are found chiefly in the hill ranges already mentioned, form an exception. These trap rocks are igneous rocks. The trap of most of the ranges in the Central Lowland was poured out in the form of lava sheets, and solidified at the surface; that of the ranges along the western border of the area was injected into fissures between the sedimentary strata.

The actual contact between the rocks of the Highlands and those of the Lowland is visible only at a few points, being generally covered by soil and vegetation. In the ravine of Roaring Brook, in Southington, the relation of the two kinds of rock to each other may be very distinctly seen.* The Lowland rocks rest upon the upturned and water-worn edges of the Highland rocks. Obviously, then, the Highland rocks are older than the Lowland rocks. Moreover, the Highland rocks had suffered the disturbance and alterations which have been already referred to, and had been subjected to more or less erosion, before the deposition of the Lowland rocks.†

Geologic Eons.— Of the four eons into which geological time is divided, the Archæan, Paleozoic, Mesozoic, and Cenozoic, the rocks of the Highlands belong entirely to the first two. It is as yet uncertain how much of the Highland rocks is Archæan and how much is Paleozoic, though probably by far the larger part of the Highland rocks belong to

* A fuller description of this remarkable locality is given on page 81, and is illustrated by Plate XIII.

† In the Pomperaug Valley, in the towns of Woodbury and Southbury, as shown in the map, Fig. 1, there is a small area occupied by rocks of the same character and age as those of the Connecticut Valley. Some further account of this interesting region is given in Chapter III.

the Paleozoic. In Archæan time it is doubtful whether there were any organisms with sufficiently developed skeletons to be preserved as fossils, for only obscure and dubious traces of fossils have been found in rocks of Archæan age. In Paleozoic time there lived a rich and varied fauna of marine invertebrates and fishes, and before the close of Paleozoic time amphibians and even reptiles had appeared. No fossils have been found in the Highland rocks of Connecticut; but it is probable that many of the schists and quartzites of the Highlands, and the marbles of the Housatonic Valley, were once fossiliferous, but have had their fossils obliterated in the alterations by which the rocks have assumed their present crystalline texture. We live in hope that further search may yet reveal here and there a trace of a fossil not quite obliterated, by which we may gain more definite information as to the age of the rocks.

Orogenic Movements.— It has been already remarked that all of the Highland rocks which show indications of stratification have the strata greatly disturbed, tilted up at high angles, and often complexly folded and crumpled. Such great disturbance of the stratification is eminently characteristic of mountain ranges, for mountain ranges are formed by the wrinkling of the earth's crust as it settles down to fit the cooling and contracting interior. The eastern border of North America has been subjected to such orogenic movements at several different times in geological history. One was at the close of the Archæan, one in the middle of the Paleozoic, at the close of the Ordovician, and one at the close of the Paleozoic. As the complete obliteration of fossils renders impossible the exact determination of the ages of the Highland rocks, it is impossible to determine how much of the disturbance which the rocks have suffered may be traced to each of these three orogenic epochs. It is not unlikely that all three of these movements had some share in the disturbance of our Connecticut rocks. Whatever effects they may have experienced in previous orogenic epochs, it is altogether probable that the rocks of Connecticut were considerably disturbed at the last of these

epochs, namely, at the close of the Paleozoic. At that time we know that the rocks of the Appalachian range, from New York to Alabama, experienced the main part of the disturbance they have suffered.

At the close of Paleozoic time it is not unlikely that there were mountain ranges of Alpine height, trending in a general north and south direction, where now we find the rugged but not lofty Highlands of eastern and western Connecticut. A mountain range is no sooner formed by the shrinkage of the earth's interior and by the crumpling of its crust, than the process of degradation begins. The chemical action of the atmosphere and the action of rain and frost crumble down the mountain summits, and the mountain torrents bear the debris to the lowlands, and much of it is ultimately carried by the rivers to the sea. There are at present no high mountains in the world which cannot be proved to have been elevated in times pretty late in the geological scale. Only young mountains can be high, for ancient mountains must have been long since degraded to mere stumps, unless a new epoch of elevation has supervened in the same region.

Connecticut in Early Mesozoic Time.— If, then, we try to make a picture of the area of Connecticut at the beginning of Mesozoic time, we can imagine lofty mountain ranges where now we see the Eastern and Western Highlands. Between these ranges was a long and relatively narrow bay or estuary, occupying the site of the Central Lowland, and extending northward about to the northern boundary of Massachusetts. Into this bay or estuary the torrents which flowed down the sides of the eastern and western mountain ranges bore the debris of the mountains; and this was the origin of the sedimentary rocks, the shales and sandstones and conglomerates, of the Central Lowland. We infer that this bay or estuary did not communicate with the ocean so freely as to be filled with salt water. No marine fossils have been found in any of the rocks of the Connecticut Valley, but remains of fishes which probably lived in fresh or brackish water, and some remains of plants and insects, and

footprints of land animals. The area was apparently a brackish-water estuary, receiving large quantities of fresh water from the mountain streams which came down on each side, and having but a narrow outlet into the ocean. The shallowness of the water over most of this area is indicated by the frequent occurrence of mud-cracks, such as form when a layer of mud left bare by a receding tide or a subsiding freshet dries in the sun. Another striking proof of the shallowness of the water is seen in the tracks of land animals which are found abundantly on many of the layers of the sandstone. The most abundant tracks are three-toed, and look, therefore, much like those of birds. It is probable, however, that in the Triassic era, in which these Connecticut sandstones were deposited, no birds were in existence. The three-toed tracks were probably made by bipedal or semi-bipedal reptiles belonging to the group of dinosauria, an interesting type of animals belonging exclusively to Mesozoic time. About midway between the beginning and the end of the deposition of the sandstones, great fissures were formed in the earth's crust, through which sheets of lava came forth and spread out extensively over the surface. There were, in fact, three of these lava sheets, the first and third comparatively thin, while the middle one was hundreds of feet in thickness. In the intervals between these lava outflows the deposit of sedimentary rock went on quietly, as it did before and after the lava outflows.

At the close of the Triassic era the region of the Central Lowland was elevated so that the bay was drained. The elevation was greater westward than eastward, so that the strata acquired at that time their prevailing easterly dip. It is probably this greater elevation to the west which determined the course of the lower part of the Connecticut River. When the region was elevated and drained, and the estuary accordingly gave place to a river, it would appear that the altitude of the country between Middletown and New Haven was greater than that of the corner of the degraded mountain range between Middletown and Saybrook.*

* For fuller discussion of the history of the Connecticut River, see page 219.

In connection with this elevation and tilting of the sandstones, there occurred also great fractures of the earth's crust with unequal elevation on opposite sides of the cracks. Such dislocations are technically called faults. Some of these faults extended beyond the sandstone area into the area of crystalline rocks; and probably many faults were made at the same time in the crystalline areas.

Connecticut in Middle Mesozoic Time.— A picture of Connecticut in the middle of Mesozoic time, just after the changes which took place at the close of the Triassic, would show, in the regions of the Eastern and Western Highlands, the degraded remnants of mountain ranges of earlier times, while the tilted and unequally elevated blocks of the Connecticut Valley region would show a type of topography not unlike that which now prevails in parts of the Great Basin in the Western United States. There we have the surface marked by a series of ranges, each showing on one side a precipitous cliff marking the elevation of that block above the block on the other side of the crack. Such fault cliffs must have been in the middle of Mesozoic time the conspicuous features of what is now the Lowland; and such cliffs must have added to the ruggedness of the mountain remnants in what is now the Highlands. In later Mesozoic time there occurred no uplifting and no crumpling of the strata; and the agencies of the atmosphere and water and ice, tending to degrade the level of the country and to smooth out its inequalities, had things all their own way.

Denudation.— Every one is aware, in a general way, that swift streams tend to erode their banks and beds, while sluggish streams tend to deposit sediment; but only those who have made some study of the subject appreciate the great effect of a slight change in the velocity of the current. The weight of the pieces of rock which can be carried by a river current varies as the sixth power of the velocity. If the velocity of a stream is doubled, it can carry a stone sixty-four times as heavy as the largest stone it could move before; if the velocity of the stream is increased tenfold, it

can carry a block a million times as large as it could carry before. The energy of the stream is the energy of a falling body; and, in accordance with the principles of physics, that energy is measured by the product of the mass into the vertical height of the fall. The conditions of a river, however, are very different from those of a body falling freely with only atmospheric resistance. Such a body falls with continually accelerated velocity; and, if the height of the fall is considerable, the body possesses at the bottom of the fall a tremendous store of energy, which may be converted into heat or may produce other striking effects. A river, on the other hand, has generally at its mouth a velocity which is almost zero, showing that its energy has been mostly expended along its course, instead of being accumulated to take effect at the end of the journey. The energy of a stream is, in fact, generally nearly all expended, partly in friction and partly in transportation of sediment. The sand and pebbles which a river carries have a specific gravity two and one-half to three and one-half times as great as that of the water, and they must, therefore, be lifted in opposition to gravity by upward eddies in the water in order that they may be transported. The larger the amount of energy which is expended in transportation, the smaller will be the residue which can be expended in overcoming friction. It follows, then, that the greater the amount of sediment the less will be the velocity of the stream; and, in turn, the less the velocity the less the competency of the stream to carry the coarser grains of sediment. As a result of these dynamic principles, we have the general law that every stream tends to shape its bed to a slope which will give the stream just sufficient velocity to carry the load of sediment which is furnished to it by rain wash and by tributary streams. That slope, for each stream, or part of a stream, is called the profile of equilibrium, and every stream tends to shape its bed to such a profile. Where the bed is too low, sediment is deposited till it is filled; where the bed is too high, the stream erodes till it is reduced to the proper profile. If, now, we assume that any part of a stream is graded ap-

proximately to its profile of equilibrium, its velocity, on an average, will be just sufficient to carry its load of sediment: on the average it will tend neither to cut nor to fill. But, if the course of the stream is a little sinuous, the velocity near the concave bank will be in excess of the average velocity, while the velocity near the convex bank will be less than the average velocity. If the average velocity is just sufficient to carry the load, neither cutting nor filling, the tendency will be to deposit sediment near the convex bank and to erode the concave bank. The sinuosity thus becomes exaggerated into a great horseshoe-shaped bend, or oxbow: as this process continues, the two ends of the oxbow come closer together, until finally, most likely in some time of freshet, the stream cuts across and straightens out its course, leaving a horseshoe-shaped lake of nearly stagnant water at the side of the main current of the stream. Thus, when a stream has worked down nearly to its profile of equilibrium, meander after meander is formed and destroyed, until a strip of country many miles wide, in case of a large river, is graded to an almost perfect plane. While the main streams of a stationary region are thus widening their valleys into plains, and this process is gradually extending towards the headwaters of the main streams and their tributaries, the action of the atmosphere and rain and frost is continually degrading the country between the streams. The divides, which in an earlier stage of development have been strongly defined ridges, are gradually flattened down to low altitudes and almost imperceptible slopes. It is evident, then, that in process of time any country that is exposed to the atmospheric and aqueous agencies of denudation, in the absence of any renewed uplift of the land, will be gradually reduced to a nearly level surface. In such a country the streams will lazily meander over the broad plains which they have formed, and which are but slightly depressed below the general level of the country. A country in such a condition is called a peneplain.

The Peneplain of Southern New England.— At the close of Mesozoic time the whole area of Connecticut, and. for that

PLATE V.

INTRENCHED MEANDERS OF CONNECTICUT RIVER IN EASTERN HIGHLAND FROM GREAT HILL (Cobalt Mountain
Photograph by L. G. Westgate.

matter, the whole area of southern New England, had been reduced to the condition of a peneplain. The remnants of mountains in the Eastern and Western Highlands, and the cliffs formed by the tilted and faulted blocks of the Central Lowland, had all been substantially planed away. The whole country was nearly flat, no part of it much above the sea level; and the rivers crawled slowly in broad serpentine curves over the great plains which they had leveled. If anyone looks at the course of the lower Connecticut, as seen in the beautiful panorama from Cobalt Mountain, or Great Hill, near the boundary of Portland and Chatham (shown in Plate V), he will see that the river, though occupying a narrow gorge, swings in broad serpentine curves. A river does not stop to make such curves when it is flowing down a steep slope towards the sea. The curves of the lower Connecticut are the curves which the river took in the old days of the peneplain. Though the country has since been elevated, and the river has had to carve a gorge, it has carved that gorge not in a straight but in a serpentine course, because it had to stay in the course which it had shaped out for itself before the uplift.

The Tertiary Uplift.— The formation of the peneplain of Southern New England was probably completed about the end of Mesozoic time. Early in the Tertiary era of Cenozoic time there came a re-elevation of the country. This time there seems to have been no folding or faulting of the strata, but a gentle uplift of the whole country into an inclined plane which, at the northwest corner of Connecticut, was about half a mile above the sea level, and which sloped gently to the southeast.* At this time, of course, the rivers entered upon a new cycle of erosion. The uplift gave them a steeper slope, a higher velocity, and a great revival of erosive power; and they began to carve out a new system of valleys in the country that had been so nearly featureless just before. In the work of this new cycle of erosion the

*This southeastward slope of the uplifted peneplain of southern New England probably represents one side of a broad and gentle arch of the earth's crust (geanticline) whose axis passed near the northwestern corner of Connecticut

unequal resistance offered by the sedimentary rocks of the Lowland and the crystalline rocks of the Highlands wrought a striking effect. On the soft Lowland sandstones the streams quickly wore down nearly to a profile of equilibrium, and began to swing sideways and to widen out their valleys into plains, while the ridges between were rapidly worn down by the action of the atmosphere and rain and frost. By these processes the region of the Central Lowland has been brought to a condition somewhat approaching that of a peneplain. An exception sometimes proves a rule; and the high ridges which mark the outcrops of the hard sheets of lava or trap emphasize the degradation which the areas of weaker rocks around them have suffered. The principal trap range in the center of the Lowland, separating the Connecticut Valley from the Farmington-Quinnipiac Valley, marks the outcrop of the massive lava sheet, the second in the series of lava outflows. While the agencies of denudation have reduced the sandstone region far towards the condition of a peneplain, the streams on the hard Highland rocks have been able in the same time only to excavate narrow trenches, and the regions between the streams have suffered but little degradation. In the case of rivers whose course is partly in the Triassic and partly in the crystalline area, there is generally a strongly marked change in the character of the valley at the boundary between the two formations. The Connecticut River above Middletown flows in a broad valley whose filling of drift has been carved into broad terraces and flood plains, while below Middletown it flows in a narrow, steep-walled gorge. Plate VI shows the head of the gorge, which contrasts strongly with the open valley shown in the foreground. The valley in the sandstones shows the character of age, that in the crystallines the character of youth, though the excavation of both was commenced when the peneplain was uplifted. It is a striking illustration of the principle that youth and age in river valleys are measured not by centuries but by stages of development. The broad features of the present topography of Connecticut are due, then, simply to the unequal re-

PLATE VI.

CONNECTICUT RIVER BELOW MIDDLETOWN.

The narrow gorge in the crystalline rocks is shown in contrast with the broad, flood-plained valley in the Triassic. Pecausett Pond divides the broad area of flood-plain in the foreground. Photograph by L. G. Westgate.

sistance of the Highland and Lowland rocks, respectively, in the new cycle of erosion initiated by the uplift which occurred at the beginning of Tertiary time. The strong crystalline rocks of the Highland areas are left today in the condition of plateau remnants gashed by innumerable valleys, while the weak rocks of the Central Lowland have been degraded to a comparatively low altitude and a comparatively smooth surface.*

If, in the post-Triassic elevation, the area of the Central Lowland had been uplifted and tilted without faulting, there would have been one substantially continuous range of trap extending from north to south through the area. It has been, however, already remarked that, at the time of this uplift and tilting, the crust was broken by numerous cracks, and the blocks on opposite sides of the cracks were unequally elevated. The principal faults in the part of the Triassic area south of Hartford were developed along cracks having in general a northeast and southwest trend; and in general the southeast side of the crack went up, and the northwest side relatively went down. Each block was tilted so that its western side was higher than its eastern; and the west side of the block on the east of each crack rose in a mighty wall above the east side of the western block. As has been already stated, all these cliffs were planed away in the formation of the great peneplain in later Mesozoic time. But these faults have a great influence upon the present topography, in that they have broken the line of outcrop of the great trap sheet, which would otherwise have been continuous, into a series of short lines which, in general, are shifted farther and farther to the east as we go southward from the latitude of Hartford. The Hanging Hills of Meriden, the range of Lamentation, the Higby-Beseck range, and the Saltonstall range east of New Haven, are thus parts of the outcropping edge of the same

* In the northwest corner of the state, the Housatonic River flows for a few miles in a valley of considerable breadth, as is the case farther north in Berkshire County, Massachusetts. In this case, the reason for the breadth of the valley is the existence of a limestone formation, which is easily eroded on account of the solubility of the material

vast lava sheet, broken apart, and arranged in parallel and overlapping lines, as the result of the great series of faults. The form of these trap hills is the simple and obvious result of the unequal resistance of the rocks and the tilting of the strata. The gentle eastward slope of the trap hills corresponds simply to the dip of the strata; the overlying sandstones have been removed, and the whole gentle slope of the hill is formed by the sheet of lava. On the west side, where the soft sandstones are exposed beneath the trap, the agencies of erosion have carved down to the general level of the valley, thus giving the almost precipitous west face which in general characterizes these hills.

The Glacial Period.— The broad features of the present geography of Connecticut were substantially completed in Tertiary time; but important modifications in detail are due to the events of Quaternary time, and especially to the action of the great ice sheet in the Glacial period. At the beginning of Quaternary time, glaciers developed in the highlands between Hudson Bay and the Saint Lawrence, which became confluent into a vast ice sheet, blending on the west with the ice sheet that covered the northern part of the great Western Cordillera. This sea of ice extended southward over Canada, New England, and the northeastern United States in general, at one point even crossing the Ohio River and extending a little distance into Kentucky. The extent of the glaciated area is shown on the map, Fig. 18, p. 230. Over most of New England the general course of the ice movement was somewhat east of south.* It scraped off the products of rock disintegration, the soils and subsoils and masses of rotten rock which had been slowly accumulating in the long ages since Paleozoic time. It ground into the solid rocks which lay beneath the rotten rock; and everywhere the rocks were marked with that smooth and polished surface and those parallel striæ and grooves which are so conspicuous whenever we uncover a fresh surface of

* See map, Fig. 19, page 239.

bed rock, and which tell their unmistakable story of glacial action.* Much of the old accumulation of soil which was thus scraped up by the glacier must have been carried into the sea. When the climate grew milder again, and the ice sheets gradually melted away, the country was left covered with a sheet of the heterogeneous deposit known under the name of *till*.† It consists partly of the remnants of the old mantle of disintegrated and decomposed rock, partly of fragments worn and torn from the underlying unaltered rocks by the action of the glacier. Its most marked characteristic is its heterogeneousness; fine sand, clay, and pebbles, and bowlders weighing many tons, are heaped confusedly together. Rarely in New England can we find in an excavation, either natural or artificial, that passage by fine gradations from solid rock through rotten rock and subsoil to the surface soil, which is so commonly observed in the unglaciated regions of the Southern States. Far more commonly in New England we find the heterogeneous mass of till resting without any gradation upon almost unaltered rock. The contrast in this respect between the conditions in New England and those in the region south of the glaciated area is shown in Plate XXV.

Some minor topographical features are connected with the distribution of the drift. While in some places the ice seems to have scraped down into the unaltered rock and shoved along all the debris, in other places the ice seems to have ridden up over great masses of till; and, when the ice sheet melted away, these great masses of till were left as low, flat domes, sometimes nearly circular in outline, but often elliptical, with the major axis of the ellipse trending nearly in the direction of the ice movement. Such dome-shaped hills are called drumlins, and in some parts of Connecticut they are very conspicuous features in the landscape. One of these drumlins, near Highland Park, in Manchester, is shown in Plate XXX.

* See Plate XXVII.

† The till, and the aqueous and aqueo-glacial deposits, more or less distinctly stratified, associated with the till, are included under the name *drift*.

There is reason to believe that at the beginning of the Glacial period the continents, at least in their northern portion, stood at a somewhat higher level than at present, and that greater elevation of the land was probably the cause of the glacial climate. Elevation of land has a certain amount of direct effect in lowering the temperature; but it has recently been shown to be probable that a general continental elevation has a much more important indirect effect upon the climate by reason of a complicated series of changes resulting in a diminution of the amount of carbon dioxide in the atmosphere, allowing a more rapid loss of heat by radiation from the earth's surface into space.* While the country at the beginning of the Glacial period probably stood at a higher level than at present, it seems certain that at the time of the final melting of the ice sheet the country was depressed to a somewhat lower level than at present. This lower level of land, of course, diminished the power of the streams for erosion and transportation, and caused the valleys which had been excavated in bed rock to be largely filled up with drift. To some extent, indeed, the valleys had come to be filled with the unstratified and heterogeneous till shoved into them by the movement of the glacier. But there are also in most of the valleys extensive deposits of sand and gravel and clay, sorted and stratified by water, which were undoubtedly deposited by the waters of the streams whose velocity was checked by subsidence, and which in parts were dammed up by accumulations of drift and converted into lakes. Between Hartford and Middletown there are extensive deposits of this stratified material rising to a height of about two hundred feet above the present level of the river. As these sediments along the lower Connecticut were probably deposited at sea level, or a very little above sea level, it may be inferred that the post-Glacial subsidence carried that part of the valley between Hartford and Middletown nearly two

* Chamberlin, in *Journal of Geology*, vol. VI, pp. 449, 597, 609, vol. VII, pp. 545, 667. The theory of climatic changes developed in these articles is not, however, universally accepted. See Hann, *Handbook of Climatology*, Part I, p. 398.

PLATE VII.

TERRACE AND FLOOD PLAIN, GLASTONBURY.

Photograph by L. G. Westgate.

hundred feet below its present level. The amount of the subsidence diminished to only a few feet at Long Island Sound, but increased northward. In the Saint Lawrence Valley marine sediments were deposited at that time which are now about five hundred feet above the sea level. In the valley of the Connecticut these river deposits attained in places a width of ten miles. It must not, however, be inferred that the Connecticut River was ten miles wide at that time. Rather must we infer that the river wandered in meanders over that belt of country, excavating here and depositing there, rapidly changing its course from time to time, and, in places, distributing itself into branches which reunited below, inclosing islands in the network of river channels.

The latest geographical change chronicled for this region is the slight re-elevation by which the country assumed, substantially, its present level. As this elevation, like the previous subsidence, was greater towards the north, southward-flowing streams gained again increased velocity and increased power of erosion and transportation; and new flood plains were accordingly formed at a lower level than the broad plains over which the river had been lately meandering. Remnants of these broad plains of drift may generally be recognized on one side or on both sides of the valley, forming those terraces which are so characteristic a feature of the scenery of New England and other portions of the glaciated region. Plate VII shows a portion of one of these terraces and the modern flood plain. Sometimes, as in the locality represented in Plate VII, we find a single abrupt descent from a high terrace to the modern flood plain, while in other places stages in the process of elevation and erosion are marked on one or both sides of the stream by intermediate terraces rising like flights of stairs. The Connecticut River, within the limits of our state, seldom shows more than one or two intermediate terraces, and generally none at all; while along the northern part of the river, in New Hampshire and Vermont, numerous terraces are often shown. Numerous terraces are shown also on many of the

tributaries of the Connecticut. The difference between the upper and the lower Connecticut, as regards the development of intermediate terraces, is probably correlated with the fact that at the time of the post-Glacial subsidence, when the great deposits of stratified drift were formed, the upper Connecticut occupied a comparatively narrow valley, while the lower Connecticut was a tidal estuary of great breadth. The condition of the formation of intermediate terraces is generally that the river, in the lateral extension of its meanders, encounters ledges of rock or hard masses of till.* This would naturally occur more frequently in the excavation of a channel in a comparatively narrow valley than in the excavation of a channel in such a mass of drift as filled the broad estuary of the lower Connecticut.

The filling of the old valleys by drift, and the consequent disturbance of the drainage system of the region, have resulted in the formation of innumerable waterfalls. In many cases rapids or falls have been produced where a stream, meandering over the broad drift plain which filled its ancient valley, was flowing on the edge of the plain where the sheet of drift was thin. In such cases, as the land rose and the river began to erode its bed, the deepening of the channel would be quickly arrested when the river in its down-cutting came to the hard bed-rock below the capping of drift. If, for some miles down the stream, the river was flowing near the middle of the drift plain, where the drift sheet was thick, a very steep slope would naturally be developed from the shallow portion of the channel carved where the drift was thin into the deeper channel carved in the thicker mass of drift. In other cases, however, streams were completely turned aside from their old courses, and forced to carve for a greater or less distance entirely new valleys.† Waterfalls or rapids would naturally be developed wherever ledges of especially resistant rock retarded the erosive action of the river. Plate VIII shows a beautiful example of one of

* Davis, *River Terraces in New England*, in *Bull. Museum of Comparative Zoology*, vol. XXXVIII.

† For an illustration of this condition, see discussion of changes of drainage in the Farmington-Quinnipiac Valley, pages 221, 251.

PLATE VIII.

WESTFIELD FALLS.

The fall began at the mouth of the gorge, in the foreground of the picture, where the sheet of trap is cut off by a fault. The gorge shows the recession of the falls.

Photograph taken under direction of W. M. Davis for U. S. Geological Survey.

these waterfalls. The fall obviously began where the hard sheet of trap was cut off by a fault. The little gorge shown in the picture below the falls has the character of an extremely young valley, and is obviously post-Glacial. Waterfalls are always short-lived with reference to the scale of geological time, since the river in time wears away the ledges which at first had resisted its erosive action, and shapes the whole length of its channel to a profile of equilibrium. In regions where the drainage system has long remained undisturbed, as in the southern states of our country, waterfalls are rare, since the rivers have had time to plane down to a profile of equilibrium nearly the whole of their channels. The innumerable waterfalls of New England and the adjacent states are the result of the disturbance of the drainage system resulting from the Glacial period.

Another effect of the disturbance of the drainage system of this region by the deposits of drift is seen in the abundance of lakes. Lakes, like waterfalls, are geologically short-lived. The inflowing streams deposit sediment that tends to fill the lakes; the outflowing streams gradually lower their channels and tend to drain them. When a watercourse has shaped itself to a profile of equilibrium, all lakes along its course will have disappeared. Some of the lakes are formed by masses of drift which have dammed up portions of old valleys. Some small ponds occupy the depressions called kettle-holes, which have been produced by the settling down of the sand and gravel where masses of ice were melting which had been buried in the drift.

One interesting effect of the changes of level in Quaternary time has been the drowning of the lower parts of our rivers, forming thereby the harbors along our coast. Long Island Sound, in fact, is a large example of a drowned river valley.

The action of the ice sheets in scraping off the soils which had resulted from the processes of rock decomposition and rock disintegration that had been going on for ages, and transporting much of that disintegrated material to the sea, probably resulted in a decided deterioration of

our territory as regards adaptation for agriculture. The changes of Quaternary time, however, have afforded abundant compensation for their injury to the agricultural interests of the State by providing us with an unlimited supply of water-power for manufactures and with harbors well adapted for commerce.

Summary.— The relation of the successive changes of geological history to the present geography and topography of Connecticut may be briefly summed up in the following statements: — The rocks of the Highlands acquired their present crystalline character in connection with the orogenic movements of Archæan and Paleozoic time. The sedimentary rocks of the Central Lowland were deposited in Triassic time, and were derived from the waste of the mountain ranges which may then have existed in the regions of the present Highlands. The draining of the Connecticut estuary occurred at the close of Triassic time. The whole area of Connecticut was reduced to a peneplain in later Mesozoic time. A general elevation of the country in Tertiary time led to the development of the broad features of the present topography. While the action of erosion on the soft rocks of the Central Lowland was able to reduce that part of the state again to a condition approaching a peneplain, in the same lapse of time the streams working on the hard rocks of the Highlands could only carve narrow, gorge-like valleys. While the broad features of the topography were shaped in Tertiary time, many minor details, such as drumlins,, river terraces,* waterfalls, lakes, and harbors, were due to the changes of Quaternary time.

* The deposits of stratified drift forming the terraces have been described on page 34 as formed in the valleys after the retirement of the ice. According to this view the terraces are remnants of plains of stratified drift which once extended across the valleys. This is probably the true explanation of many of the terraces. But recent investigations show that probably some of the terraces (particularly in the lower or estuarine portions of the larger rivers) were formed as delta deposits along the sides of the valleys, while tongues of ice extending beyond the general line of the receding ice sheet still occupied the central part of the valleys.

Chapter II

The Crystalline Rocks

By

HERBERT ERNEST GREGORY

THE CRYSTALLINE ROCKS.

PART I.

GENERAL PRINCIPLES.*

INTRODUCTION.

With the exception of the rocks of Triassic age, described in Chapter III, the entire state of Connecticut is underlain by crystalline rocks of very great antiquity. As indicated on the maps (Fig. 1, page 19, and Plate XIV), the Triassic areas cover about 1,000 square miles, and the *Ancient Crystallines* occupy the remainder of the 4,990 square miles which make up the state. Thus, the crystalline rocks may be said to constitute the floor of the state and to be the characteristic rock formation. They everywhere surround and underlie the sandstones and lavas of a later age.

This widespread distribution of crystalline rocks as compared with unaltered sedimentary deposits is characteristic of New England as a whole, as well as of the state of Connecticut. Small areas of slightly changed sediments are found in Rhode Island, and in central and eastern Massachusetts. Vermont and New Hampshire also have representatives of this class of rocks. Maine has fossiliferous sediments in several localities, particularly in the Aroostook region. Considered as a whole, however, rocks other than crystalline are rare in New England; and the region is clearly a geological province of metamorphosed, crystalline rocks, varied here and there by areas consisting of other types.

The ancient rocks of the crystalline tracts differ radically from the sandstones and traps of the Connecticut and Pomperaug valleys. As a rule, we find simplicity and reason-

* It is here taken for granted that the reader has a knowledge of elementary geology, at least so far as to be acquainted with the chief mineral species and common rocks, the geological ages, and the main geological processes.

able uniformity in the latter, while complexity and variety characterize the former. The method of origin and history of the sandstones are fairly well known, yet we are ignorant of the meaning of many structures in the crystallines, and the origin of certain rocks in Connecticut is shrouded in mystery. An explanation of sedimentary rocks requires a knowledge of the forces operating at the present time on the surface of the earth. It is necessary to understand the action of rivers, winds, ice, etc. A complete understanding of the crystallines involves a knowledge of the forces which are at work within the interior of the earth, as well as an understanding of the chemical and mineralogical composition of the rocks as they exist. Much detailed study is required; and the cooperation of physicists, chemists, and geologists is necessary to solve the problems presented by metamorphic rocks. It is but fair to state that data are not at hand and methods have not as yet been developed which make it possible completely to understand the composition, structure, origin, and history of many rocks within the state. Geological science is not sufficiently advanced to solve the problems offered by some of our most widespread rock formations. The reader should therefore not be discouraged at his inability fully to understand the geology of his locality, and to recognize readily the innumerable varieties of rock which he finds in the ledges or scattered along the roadsides throughout the area of the ancient crystallines. An additional difficulty confronts the student of Connecticut geology in that some of the bowlders built into fences or strewn over the field cannot be traced to their parent ledge within the state, and a knowledge of the geology of the regions to the north may be necessary before the history of a roadside pebble can be interpreted.*

Although it is impossible to give a complete account of the origin and history of the ancient crystallines, many facts about them are known; and it is the purpose of this chapter to present these facts, and to explain the characteristic

* These bowlders which have been brought to the state by the great ice-sheet of the Glacial period are explained more fully in chapter IV.

features of the geological formations found within the state both east and west of the Triassic areas.

SEDIMENTARY, IGNEOUS, AND METAMORPHIC ROCKS.

For the convenience of students of science, rocks have been divided into three classes: sedimentary, igneous, and metamorphic. Each of these classes is represented in Connecticut by many varieties.

Sedimentary Rocks.— The sedimentary rocks are those which have been laid down by water. They are muds, sands, gravels, and ground-up shells, which have been cemented and pressed into solid rock. Such are the shale beds at Saltonstall, Durham, and Bloomfield; the sandstones at Portland, Tariffville, and Windsor; the conglomerates at Fair Haven and Meriden; and the thin beds of limestone west of the main lava ridges in Northford and Southington. The shales, sandstones, and conglomerates are made of fragments of other rocks, and their composition and structure reveal their history. Sandstone tells the story of a preexisting land area, of the action of frost, wind, and ice, which disintegrated the original rock, and of moving water in the form of rivers or waves which carried the broken material to a place of rest. The cement between the individual grains tells of the presence of water carrying mineral matter in solution. Thus it is with other sedimentary rocks; each contains within itself a more or less legible life history.

Igneous Rocks.— Igneous rocks have been once molten and have solidified by cooling. They are therefore typically composed of crystals, as compared with sedimentary rocks, which are formed of broken fragments. In accordance with their chemical and mineral composition, igneous rocks are divided into a great number of species — granite, syenite, diorite, basalt, etc. The conditions under which these rocks cooled have made a great difference in their texture; hence we find fine-grained granites like those from Millstone Point and coarse-grained rocks like those

quarried at Stony Creek. The history of an igneous rock is revealed by an examination of its composition, texture, and structure; thus, for example, it is known that the diabase of East Rock at New Haven was forced into the sandstone and cooled below the surface of the earth; that the rock of Talcott Mountain is basalt, formed on the surface as a lava flow; that the granite rock quarried at Waterford cooled at a very great depth below the surface.

The sedimentary rocks of Connecticut are confined to the Triassic areas — the Connecticut Valley and the Pomperaug Valley. The unchanged igneous rocks have a large development within the Triassic, and are present in small amounts throughout the State. The rocks of these two types require no explanation beyond that given in ordinary text-books. The great mass of Connecticut rocks, forming the ledges and distributed as loose bowlders, belong to the third class, the metamorphic, and require special explanation.

Metamorphic Rocks.— Metamorphism is a term introduced by Lyell as the name of a process by which rocks are profoundly changed from their original condition. The rocks resulting from such changes are called *metamorphic*. The early geologists believed that metamorphic rocks were always modified forms of sedimentary deposits, but it is now known that the original rock may have been either sedimentary or igneous, and metamorphic rocks themselves may be changed again and again. Metamorphism is in general a change in the direction of greater induration and more complete crystallization. The amount of metamorphism which takes place may be slight, as in the case of a clay hardened by contact with heated rock. The great areas of metamorphic rock, however, have undergone much greater changes in texture; composition, and structure—changes so far-reaching that in many cases it is impossible to determine the nature of the original rock. Changes of this sort have occurred in the Connecticut crystallines, and their appearance is so altered that the original rocks and their metamorphic

equivalents would be naturally classed as unrelated types. They have been thus classed in the past, as the older geologic maps will show, and it is reasonable to expect that eventually groups of rock which we now distinguish will be found to be different phases of the same formation. Only an expert geologist is able to see an ancient diabase in the chlorite schist of Milford, and to recognize that the micaceous rock of Bolton Notch formerly existed as mud.

A striking feature of the Connecticut crystallines is the absence of fossils. So great have been the changes induced by heat and pressure that all traces of former life have been destroyed. Not even a fragment of a fossil has been found in these rocks within the limits of the state. The far-reaching importance of this fact is at once seen when we realize that fossils are a means of finally determining the geological age of rocks, and that, owing to the absence of these remains, the age of the crystallines in Connecticut is unknown. We have proof that the metamorphic rocks are older than the sandstones, which are of Triassic age, because they lie unconformably beneath the strata of the Farmington Valley; but whether they are mostly Cambro-Silurian or Carboniferous, or whether some are Archæan, and representatives of all the Paleozoic ages are present, is not known. This absence of fossils makes of little value the ordinary methods of determining the relations of the various formations, and we must learn what we can from a study of the composition, texture, and structure of the rocks themselves.

PRINCIPLES OF METAMORPHISM.

Because the structure of metamorphic rocks is so entirely different from that of sedimentary and igneous types, and because their origin is due to forces which have not operated in the case of the unmetamorphosed varieties, it may be found helpful to discuss briefly the physical and chemical principles underlying metamorphism.*

* For a complete discussion of these principles, see Van Hise, *A Treatise on Metamorphism*, U. S. Geological Survey, Monograph XLVII

Contact Metamorphism.— Metamorphism may result from exceptional heat applied to rocks, in which case the process is largely one of expulsion of water and hardening and discoloration, with partial fusion. The process is well exhibited at the margin of the dikes cutting the sandstone of the Fair Haven tunnel, where the sandstone is hardened by contact with the molten material; and is very much like the process of brick-making. Elsewhere in the area covered by the Triassic rocks this process of local metamorphism by contact with hot rock is well shown.

Metamorphism usually, and always on a large scale, is the result of heat combined with great lateral pressure. The metamorphic crystallines of Connecticut, as well as most other metamorphic rocks, are the result of widespread activity on the part of forces acting below the earth's surface.

Movements of Rock under Pressure.— In shrinking, the earth requires a continuous adjustment of the outer zone to the interior; and various minor adjustments are due to the fact that parts of the earth's surface are weighed down by the accumulation of sediments, while other parts are having material removed by erosion. The result of these and other causes is that rocks are continually subjected to strain, and when found in nature are much or little affected, according to the amount and the character of the thrust. The chief factors which control the deformation of a rock mass under a given thrust are the thickness, strength, and composition of the rock, and the character and thickness of the materials which enclose it above and below. The pressure exerted by thousands of feet of strata causes deeply buried rock masses to behave quite differently from those at the earth's surface. In accordance with these principles three zones within the earth are distinguished; namely, the zone of fracture, the zone of flowage, and the zone of combined fracture and flowage. In each of these, rocks are differently affected and certain characteristic structures are developed.

Zone of Fracture.— When rocks at the earth's surface are subjected to lateral pressure, they break, and leave crevices, small or large, between the broken parts. This condition holds true of rocks below the earth's surface down to a depth where the weight above them is greater than the strength of the rock to resist. The fracture may appear at the surface as a fault, joint, or mass of crushed rocks, held firmly in place. Often the fractures are innumerable and extend in one direction over a wide area. Rocks so located in the earth that they break when subjected to pressure are said to be in the *zone of fracture.* The depth of this zone below the earth's surface varies with the strength of the rock; but even for the most rigid rocks there comes a place, never at a great depth in comparison with the earth's diameter, where the weight of the rocks above exceeds the ultimate strength of the rock beneath; and here no joint, or fracture, or cavity of any sort can exist. In the case of soft shales, this depth may not exceed 2,000 feet, while in the strongest rocks known it is probably not over 30,000 feet. At these depths no permanent crevice can exist, and if a fracture should occur the parts would be soon actually welded together.

The sandstones and lavas of the Connecticut Valley are now in the zone of fracture, and were in that zone when the displacements occurred which destroyed the continuity of the strata. They are traversed by innumerable faults, zones of brecciated rock, and systems of parallel joints. They have adjusted themselves to the lateral strain by breaking and by the slipping of the broken parts past each other. It is partly to this fact that we owe the preservation of the Triassic strata, for the sandstones and lavas have been broken and depressed below the general level of the country, and hence preserved from erosion during the long periods that have elapsed since Triassic time. The metamorphic crystalline rocks likewise are now in the zone of fracture, but their character and structure were already present when they were brought to that zone by erosion of the overlying mass.

Zone of Flowage.— Within the earth's surface, at a depth of about 30,000 feet, the conditions are very different from those just described. The weight of the strata above exceeds the strength of the rock to resist, and cracks and crevices cannot form. The rocks are everywhere subjected to compression, and the materials composing them attain equilibrium by moving from a place of greater to one of less pressure. The material composing the rocks adjusts itself, not by sudden breaking and slipping of one part past another, but by *flowing* quietly and without shock to its new position. In their movements deeply buried rocks obey the laws of hydrostatics, not the laws of solid bodies. Under the great weight from above the rocks yield and flow, and adjust themselves under lateral pressure like tallow or wax. Rocks under these conditions are in the *zone of flowage.*

It is to be expected, of course, that rocks of different character will behave differently in the zone of flowage as well as in the zone of fracture. A strong, thick stratum will flow with less ease than a thin, weak bed; and a stratum which is protected by strong beds above and below will act very differently from one not so situated. This conception of the complete plasticity even of the firmest and most resistant rocks, when deep-seated and subjected to pressure from the sides, is essential if one is to understand metamorphic rocks. Minute plications, and structures showing mashing, welding, and other evidences of adjustment by flowage, are characteristic of the Connecticut metamorphics. These structures can be seen from one end of the state to the other, when a ledge as a whole is looked at, when a hand specimen is examined, or when a thin section is viewed under the microscope. The perfection of structure of this type is remarkable. As is shown in Plate IX, Fig. 1, the minute particles of mica and other minerals form a stream which takes a general direction, but, like a stream of water, bends or divides to adjust itself to the obstructions in its path. The simile of the stream must not be understood to

PLATE IX.

Fig. 1. MICROSCOPIC SECTION OF CRUSHED QUARTZ PORPHYRY, SHOWING ADJUSTMENT OF MINERAL PARTICLES BY FLOWAGE.

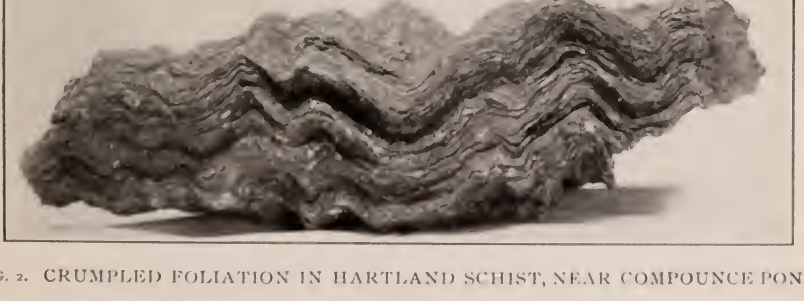


Fig. 2. CRUMPLED FOLIATION IN HARTLAND SCHIST, NEAR COMPOUNCE POND.

imply that the particles have reached their position by moving continuously in one direction, for adjustments have taken place wherever the pressure has permitted. The minute flakes of mica form parallel bands which wind in and out around the harder kernels, along lines of dragging or squeezing, thus allowing the rock to flow.

The rocks shown in Plates IX and XII, though now exhibited at the surface of the earth, are believed to have been formed in the zone of flowage, some miles below the surface, and will serve as illustrations of schists and gneisses so common within the state, which are believed to have been formed within this same zone. If these views are true, they give some clew to the amount of erosion which has taken place throughout southern New England. (See page 28.) Miles of strata must have been removed to expose these rocks formed in the zone of flowage.

The Zone of Fracture and Flowage.— Because rocks are not uniformly strong, and because they may be subjected to different conditions of pressure, it will be readily understood that some strata may be in the zone of flowage, while others, buried to the same depth, may be in the zone of fracture. At a given depth weak rock would adjust itself by flowing, while stronger rock would break; for example, a bed of shale may be in a state of plasticity when much nearer the surface than a bed of firmly cemented sandstone. Certain beds may be completely metamorphosed, while adjoining beds retain much of their original character.

In trying to unravel the tangle of metamorphic crystalline rocks, search is made in the field for the more recent beds, in the hope that some structures may have outlasted the changes that have occurred. Part of a rock may be in the zone of fracture, while other parts of the same rock yield by plastic flow. Certain formations occurring in Connecticut, as the Brimfield schist, show little fracture, and yet the microscope reveals the fact that individual grains of quartz have been broken and recemented. The rock has

been plastic and has yielded without breaking, or has broken, in accordance with its position and the nature of the stress applied. The structures of such rocks were developed in the *zone of combined fracture and flowage.*

The Three Zones Compared.— In order to understand the relation of these three zones we may assume, as suggested by Van Hise, an imaginary homogeneous rock extending from the surface to an indefinite depth. When such a rock mass is subjected to lateral pressure, the parts near the surface will be broken into blocks by faults and joints. Here the individual particles composing the rock are little affected except immediately along the joints, and the texture of the rock and its fossil contents are little modified. Farther below the surface, the lines of fracture become closer together, and the blocks are reduced to slabs and then to thin layers. Deeper down every particle of rock takes part in the deformation. The rock is granulated and partially recrystallized. Still farther down recrystallization becomes the dominant process, and the rock loses its former nature entirely and becomes metamorphosed. It may then be classed as a crystalline schist. There is, of course, every gradation from one of these stages to another. A case is described from the Coast Range of California, where there "are seen all stages of transition between brecciated igneous rock and a crystalline schist." "In passing from the breccia to the schist, one first finds, about the blocks of igneous rock which have their characteristic textures, mere films of schists. Passing farther toward the schist, an intermediate stage is found, in which unmashed blocks lie in a schistose background or matrix. But a short distance from this place is the completely altered schist, in which no unmashed fragments remain." * The same phenomena may be observed in the Appalachian districts of Tennessee. Many of the Connecticut crystallines were formed in this zone of fracture and flowage, or through

* Van Hise, in *Bull. Geological Society of America*, vol. IX, p. 313.

erosion have been brought to this zone from that of flowage. They exhibit fracturing and folding both on a large scale and microscopically. Unfortunately no localities have been found where it is possible to trace these schists through the different stages, from their original unaltered state to their present crystalline form.

STRUCTURE OF METAMORPHIC ROCKS.

The metamorphic crystalline rocks of Connecticut exhibit structures very unlike the sedimentary strata of the central belt. They are everywhere seen to be in layers, usually very thin, and to present a banded appearance. When seen from above, the ledge appears to be traversed by innumerable lines, which are the edges of planes along which the rock may be divided into a multitude of slabs or sheets. When viewed from the side, as in railroad cuts (for example, along the line of the Highland Division or the Central New England Railroad), the sheets seem to be inclined at a high angle, usually nearly vertical. Thus, rocks produced by regional metamorphism have the appearance of being sedimentary beds that have been deposited in a horizontal position and then turned up on end by some movement within the earth's crust. There is one striking difference, however, between these layers and sedimentary beds: namely, the metamorphic rocks are composed of more or less complete *crystals,* close pressed and interlocking, instead of worn *fragments* of material cemented into solid rock. Furthermore, this division into planes, or apparent bedding of the crystallines, does not indicate that the rock was deposited in layers; but it is a new structure which has been developed in the rock by the process of metamorphism. So far as the writer has observed, there is not within the state a metamorphic rock whose present division into sheets is perfectly coincident with the structure of the original unmetamorphosed sediment.

In order to understand this difference between real and apparent bedding, it is necessary to examine the princi-

pal structures found in metamorphic rocks, and also to consider their mode of development. One of the characteristic properties of a metamorphic rock is its capacity to break more easily in certain directions than in others. This property is called *cleavage*. The same name is applied to a property shown in minerals. For instance, when calcite is broken, the fragments are not irregular and without definite form, but are rhombohedrons, and their shape is determined by the position of the cleavage planes in this particular mineral. When a metamorphic rock is broken, it is seen to part easily along certain lines and with difficulty along others. Yet the use of the same name should not lead to a confusion of the two phenomena. Minerals cleave because of a definite arrangement of their molecules; rocks cleave because of the parallel arrangement of their constituent minerals.

When, as a result of cleavage, a rock has the capacity to separate into parallel layers, or laminæ, it is said to possess *slatiness, foliation,* or *schistosity*. A *slate* is a crystalline rock which has the property of cleavage and separates into layers with relatively smooth surfaces. A *schist* also has the property of cleavage, but the surfaces separating the laminæ are usually more or less rough. In the slate the component crystals are of small size — even microscopic; in the schist the mineral particles are larger. Slatiness and schistosity are thus seen to have essential characters in common, and there is every gradation between the two.

A word may be added here to call attention to the confusion existing in the use of the words *slate* and *shale*. Both of these rocks break into thin layers with quite even surfaces, and hand specimens of the two appear superficially much alike. Their texture, origin, and history, however, are widely different. Shale was formerly mud deposited by water, and is composed of fine broken particles cemented together. It has never been deeply buried nor subjected to great heat and pressure. The laminæ of which it is composed are of the same thickness and made of the same ma-

terials as when first deposited by the quiet water. Slate, on the other hand, owes its texture, structure, and composition to heat and pressure. It is metamorphic, not sedimentary. It is composed of crystals, not of broken fragments. Its laminæ are due to movement under pressure, not to its method of deposition by water. Slate may be made from shale or from other rock. Slatiness may be developed while there still remain traces of the material and structure of the original rock. There is no slate in Connecticut within the Triassic area, but brown and black shales are abundant. No shales are found in the crystallines, but slates are developed in several places.

Origin of Schistosity.— We may now inquire briefly how schistosity and slatiness are brought about. In the first place, it is to be remembered that these phenomena are produced only in the zone of flowage where crevices cannot exist. No opportunity is there offered for surface changes, and little or no chance for foreign matter to be brought in, so that the great alteration which occurs must be due to chemical reaction. The rock is subjected to heat and pressure in such a manner that part after part passes into solution, and incessant changes of position are taking place. In this way the material can adjust itself to the changing form of the rock mass. In this connection the importance of the small amount of water contained in the rock is very great, as it aids in dissolving old crystals and in recrystallizing the amorphous material. Schistose rocks are composed of innumerable particles having the longest diameters or easiest cleavage or both in a common direction. The minerals are for the most part made from the materials in the original rock, and the new minerals are flattened by great pressure and forced into parallelism. Some of the original flat minerals are also rotated into parallel position. The net result is that most of the minerals have a parallel arrangement, and the rock accordingly splits along these cleavage planes more readily than in other directions. The most important of the minerals that fall into

parallel position are the micas. The next in importance are feldspar, amphibole, and chlorite. Rocks containing abundant mica — i. e., mica schists — make up a large part of the crystalline areas of Connecticut; and wherever schistosity is well developed, crystals of muscovite and biotite are large and closely parallel in position.

The process by which new materials form by recrystallization may be illustrated by the micas. Muscovite and biotite are comparatively rare in the sediments which are most readily transformed into mica schist. For instance, there may have been no mica whatever in the shales and sandstones from which the Hoosac and Bolton schists developed, and yet at the present time mica is a characteristic part of these metamorphic rocks. Soils, clays, and shales contain elements from which mica may develop. Some of the necessary constituents are found in feldspar, and some in various hydrous minerals, as kaolinite, chlorite, limonite, etc., and these minerals are commonly present in the rocks from which mica schist develops. The schist itself, however, may be entirely free from such minerals. During the process of metamorphism the hydrated minerals have been taken into solution, and from this solution the mica crystals have been developed, and the material has been thus rendered more compact. When the little crystalline grains of mica begin to form, their position is controlled by the pressure to which the rock is subjected; hence, as more and more material is deposited to complete their crystalline outlines, the micas form in parallel position. Micas are thus seen to be a continuous growth by recrystallization during the process of metamorphism. But it seems essential that the chemical process be controlled by dynamic action.

The schistosity which characterizes Connecticut crystallines is due to chemical action carried on in the zone of flowage under mechanical pressure, and is an entirely new structure, bearing no definite relation to that present in the original rock.

Throughout Connecticut the planes of schistosity are, roughly speaking, north-south to northeast-southwest, and

the lateral pressure in the earth's crust must have come from the southeast. The planes of schistosity dip generally to the southeast, so that the tops of the metamorphic layers have been pushed to the northwest or their bottoms to the southeast. There are, however, many local variations; and this simplicity of structure is interrupted by the presence of intrusive masses of diorite, granite, and other igneous rocks, about which the schistose planes seem to wrap. In such cases the direction and dip of the schistose layers assume various attitudes. For instance, at Bristol, the planes of schistosity lie in nearly every direction of the compass in order to adjust themselves to the rounded mass of granite-gneiss which underlies the city.

Fissility.— The surfaces of parting which constitute the cleavage planes in a rock may be present without being apparent to the eye. Weathering, however, often serves to bring the planes of separation into prominence, and to convert them into definite cracks. Such open cracks, as described below, may by subsequent changes be recemented.

Strictly speaking, when rocks are actually parted, instead of possessing merely the capacity to part, they are said to be *fissile* or to possess *fissility;* and many of the Connecticut schists may be thus characterized.*

When for any reason a parting of the rock takes place along planes of schistosity, an additional factor enters to complicate the structure. In the crevices between the laminæ new mineral substances may be deposited by water or injected from an igneous mass so as to fill the space completely. The result is a banded rock which has the appearance of a true metamorphic gneiss or schist, but which has been developed in a different way. These seams of infiltrated or injected rock may be of unlike substances and vary from mere films to layers an inch or more in thickness. In

* While cleavage planes may, as above explained, be converted into open cracks by subsequent changes, when the rocks are brought nearer to the surface by erosion, it is also true that, if the rocks at the time they are subjected to pressure are in the zone of fracture instead of being in the zone of flowage, the structure produced by pressure will be fissility instead of cleavage.

some cases these seams are really small dikes, and are offshoots from some granite mass in the neighborhood. Commonly they are lenses or films of infiltrated matter, approaching the character of true veins. In either case the structure may be so delicately formed as to follow the most minute plications in the original rock. Care must be taken not to confuse such injections or infiltrations with metamorphic laminæ produced by lateral pressure.

Joints and Faults.— Fissile rocks have abundant partings running in the direction of schistosity, which are to be considered as open cleavage cracks. The planes of cleavage were originally produced by pressure at right angles to their present alignment, and the fissility resulted from the opening of cracks by release of pressure and weathering or from other causes. The schistose and slaty rocks are quite commonly fissile, especially when exposed for some time to surface agencies. But the rocks may also show divisional planes in other directions than that of the cleavage.

Joints are the ordinary cracks seen in ledges. Very rarely, indeed, are they absent from rocks exposed at the surface. Commonly there are two or more sets, the two most prominent sets being often roughly at right angles to each other. The rock surface may be thus divided into polygonal areas. In regions like Connecticut, where the rocks have been intensely metamorphosed and have experienced many movements and much disturbance, the joints are very numerous and prominent, and run in many directions. All planes of actual separation in rocks, whether of fissility or of jointing, are produced near the earth's surface and not at great depths, and are the results either of compression or of tension in rocks. The openings are usually regarded as results of tension.*

When movement has taken place along a joint plane or

* For a full discussion of the joint and fault system of Connecticut with its resulting effects on topography, see the writings of W. H. Hobbs, especially the following:— *Newark System of Pomperaug Valley* (*U. S. Geological Survey, Twenty-first Annual Report*, Pt. III); *Geological Structure of South Western New England* (*Am. Journal of Science*, series 4, vol. XV, pp. 432-449); *River System of Connecticut* (*Journal of Geology*, vol. IX, pp. 469-485).

plane of fissility, so that the rocks on one side are depressed or elevated in respect to those on the opposite side, the displacement constitutes a *fault*. Because of similarity of material on two sides of the fault plane, such structures are rarely noticeable in the crystallines. In some cuts, however, the crumbled rock shows plainly that a movement has occurred; and smoothed surfaces, known as "slickensides", and indicating slipping along joints, are visible in nearly every quarry in the state. The igneous and sedimentary rocks of the Triassic formation are much better suited to exhibit fault structures than are the ancient crystallines. In metamorphic rocks, however, there is abundant evidence that faulting has taken place. Cliffs occur which seem to owe their position to faulting, abrupt changes are noted in the direction of boundary lines of certain formations, and crushed rock and slickensides are found along the lines of breaking.*

MINERALS IN METAMORPHIC ROCKS.

In this chapter it is not intended to describe the rock-making minerals, but a brief explanation of those most commonly met with in Connecticut, which owe their existence and form to metamorphism, may be found helpful to the reader who is not a student of mineralogy.

The various forms of quartz found in metamorphic rocks differ in no essential particulars from quartz found in sedimentary rocks, except that complete or broken crystals occur instead of rounded grains. The quartz is either original, or has been produced by metamorphism of feldspar.

Feldspar is the most abundant constituent of crystalline rocks; and, for that matter, the most abundant mineral found at the earth's surface. It has many species and varieties, which are complex chemical compounds; and when a rock containing this mineral suffers alteration numerous changes take place. Feldspar may alter into quartz and muscovite. In this case the muscovite commonly occurs as

* See page 200, for a discussion of faults in the Triassic area.

minute flakes which form a sort of film over the rock surface along planes of foliation, as in the schist at Compounce Pond and in Tolland. Feldspar alone may change to quartz and muscovite. With the addition of magnesium and iron, feldspar may change to quartz and biotite, or to quartz and chlorite. In other cases quartz and epidote result. Thus it appears that, when muscovite or biotite or quartz appears in metamorphic rocks, it may be an entirely new mineral, and have been represented in the original rock by feldspar.

Hornblende alters to biotite or to chlorite, and from this to zoisite or epidote.

Angite commonly alters to hornblende, and then to chlorite, biotite, etc.; or changes directly into these minerals without passing through the hornblende stage.

Biotite and muscovite of sedimentary and igneous rocks are usually unchanged by metamorphic action; but the great abundance of these minerals in schists and gneisses is not due to their presence in the unchanged rock mass, but to the fact that they are so readily produced from other minerals, as shown above.

The calcium carbonate of metamorphic rocks is crystalline in texture, and may occur as calcite, or part of the calcium may be replaced by magnesium and dolomite be produced. The calcareous rocks of the Canaan and New Milford districts are dolomitic. Properly speaking, this rock, of which the State Capitol is built, is a dolomitic *marble.* The original limestone has suffered metamorphism which caused the entire mass to be crystallized. A common alteration of dolomite is into tremolite, a variety of amphibole. Tremolite crystals frequently occur in the dolomitic marble of Connecticut; and in places, *e. g.,* the camp-meeting ground near Canaan, they weather out of the marble and may be gathered in large numbers.* Hornblende also results from alteration of dolomite, and some of the black hornblendic bands occurring in the crystallines may be the pres-

* The crystals at this locality have the form of pyroxene, though they have assumed in greater or less degree the cleavage structure of amphibole. They seem to have been first formed as crystals of diopside, and then undergone a change of molecular arrangement converting them into tremolite.

PLATE X.

FIG. 1. PORPHYRITIC TEXTURE IN GRANITE-GNEISS, DERBY.

The phenocrysts are feldspar.

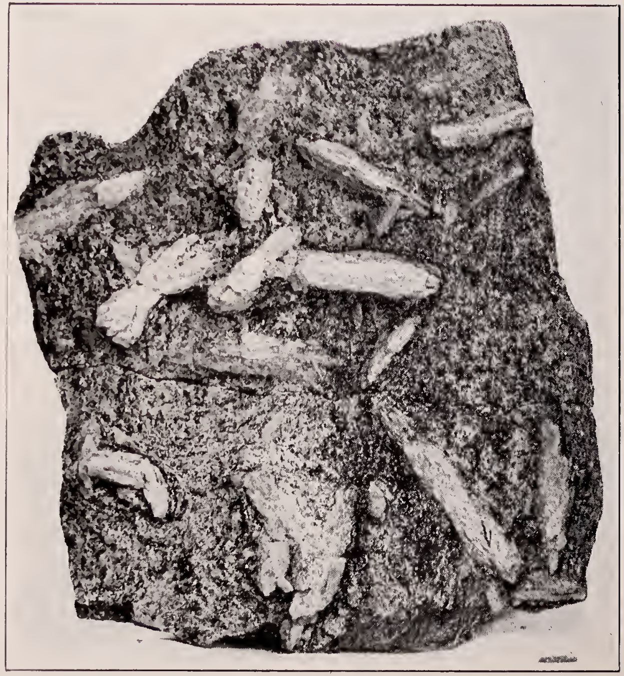


FIG. 2. PORPHYRITIC TEXTURE IN SCHIST, DEVELOPED FROM SEDIMENTARY ROCK, WEST STAFFORD.

The phenocrysts have been brought into prominence by weathering.

ent representatives of original limestones which became marble and then hornblende schist and gneiss. The change from marble to hornblendic rock is a complex process, and involves the addition of silicon, aluminum, iron, and magnesium.

In addition to the minerals which occur commonly in sedimentary, igneous, and metamorphic rocks alike, there are a number that assume a prominent rôle in metamorphic rocks alone. Those most abundant in Connecticut are: garnet, cyanite, andalusite, staurolite, fibrolite or sillimanite, chlorite, serpentine, and epidote.*

Porphyritic Textures.— For the most part metamorphic rocks are made up of crystalline grains which differ little among themselves in size, none of them being large. Certain of the schists and gneisses, however, exhibit a marked variation from this structure. In these rocks one or more minerals have crystallized on a much larger scale than the others, and the rock appears as a mass of medium-sized crystals, among which large ones are scattered. The larger crystals, called *phenocrysts* (*i. e.,* easily seen crystals), may be hundreds of times larger than those in the ground-mass, and may be several inches in diameter. In Connecticut, the more important minerals that show themselves as phenocrysts are feldspar, garnet, staurolite, cyanite, and hornblende. The structure is well seen in the Prospect gneiss and in the Bolton and Hartland schists (see Plate X).

The phenocrysts of the porphyritic gneisses and schists usually have well defined crystal outlines, showing little evidence of pressure, and must have been developed after the date of severe metamorphism. Furthermore, the crystals are not always arranged in accordance with the planes of schistosity, but seem, in part, at least, to have developed after the structure was formed. In case the phenocrysts developed at a later date than the development of the schistosity, they seem to be the result of absorption and en-

* For a description of these minerals the reader is referred to standard treatises on mineralogy, and particularly to E. S. Dana's works: *Minerals and How to Study them; Text-Book of Mineralogy, System of Mineralogy.*

largement of crystals during the period of relative quiet which followed the great dynamic forces that produced metamorphism. Great heat and moisture in the rocks would be necessary conditions. In those cases in which further metamorphic change has occurred after the formation of the phenocrysts, the crystals are seen to have been drawn out along the planes of schistosity, and often to have assumed a lenticular shape, and to have had their ends drawn out into lines of broken fragments. This is well shown in the porphyritic gneiss about Derby.

Many phenocrysts in gneisses, however, are older than the structures produced by metamorphism. Porphyritic structures belong also to igneous rocks; and many porphyritic gneisses are igneous rocks which have been metamorphosed, but not to an extent sufficient to destroy the original porphyritic structure. A porphyritic gneiss developed from an igneous rock with porphyritic texture thus has a life history made of a number of stages. In the original molten mass (magma) large distinct crystals formed, which floated in the remaining liquid material. A change then took place which caused the rest of the mass to solidify more quickly and therefore to form small crystals. The rock may have remained for some time as an igneous porphyry, but was finally squeezed and stretched by the forces which converted it into a porphyritic metamorphic rock. Thus the rock reveals within itself much of its history.

SOME OF THE PRINCIPAL METAMORPHIC ROCKS.

The theoretical principles briefly treated above may perhaps be better understood by noting the characteristics of the principal kinds of metamorphic rocks and their stages of development from unaltered sedimentary or igneous rocks to their present state. The types represented in Connecticut are marble, quartzite, slate, schist, and gneiss. The last two rocks are the most widespread in the state, and, in fact, make up a large part of the floor of New England.

Marble is metamorphosed limestone, and the change occurs usually where there has been great pressure and strong dynamic action. The chief mineral constituent of limestone is calcite, but the calcium may be partly replaced by magnesium, forming dolomite. Metamorphism results in a complete crystallization of the grains of calcite and dolomite, and the production of a rock which is a mass of calcite and dolomite crystals. Marble rarely develops a schistose structure or slatiness. It is so soft and so readily taken into solution that the grains in the original limestone have adjusted themselves by recrystallization and by moving along cleavage planes. The Stockbridge limestone (see page 87) is dolomitic, and, though closely folded in with schists, shows little schistose structure. Limestone is no exception to the rule that sedimentary rocks contain impurities. From these impurities metamorphism develops minerals which commonly occur in marbles. Garnets are found, also pyrite and other iron compounds; micas may show abundant development; pyroxene and various varieties of amphibole, especially actinolite and tremolite, also occur. Impure limestone in certain localities has been altered to hornblende schist or gneiss, and calcareous hornblendic bands occur in connection with the other crystalline rocks of the state. So far as known, the Connecticut marble is all dolomitic, and it varies much in the degree of its purity. The rock quarried in Canaan is perhaps the best obtainable, but its impurities are points of weakness.

Quartzite is a metamorphic sandstone. In the original sandstone rounded grains of quartz are held together by a cement which is commonly silica, iron oxide, or calcium carbonate. In the process of metamorphism parts of the quartz grains are dissolved, and the silica is redeposited in the spaces between the grains, or is added to the grains in such a manner as to produce the crystalline form peculiar to quartz. The sandstone is thus so thoroughly indurated that, when broken, the fracture passes more readily through the original grains than through the cement. There are, of

course, all stages of metamorphism, from hardened sandstone to quartzite so vitreous as to be scarcely distinguished from the quartz occurring in veins. The amount of silica required to convert sandstone into quartzite has been estimated at one-third to one-sixth the amount of the original grains. Where quartzite is a widespread formation, the amount of new material which owes its existence to metamorphism is therefore enormous.

The formation of quartzite by "cementation," as indicated above, does not require deep burial, nor pressure sufficient to produce schistose structure. When, however, quartzite is buried so deeply as to reach the zone of flowage, and is subjected to mashing by lateral thrust, schistosity is developed, and the rock is traversed by planes of cleavage, and passes into a schistose quartzite and finally into a *quartz schist.* In the first stages of the process the quartz grains are flattened and somewhat rearranged, lines of fracture appear, and finally the quartz loses its crystalline orientation and becomes a mass of broken grains. This formation of small fragments of quartz from crystals takes place most readily when little or no water is present in the rocks. Simultaneously with this granulation process new quartz and perhaps mica may develop in the spaces between the grains, from the impurities in the original sandstone. The result is that films of mica and occasionally other minerals form along the planes of foliation, and the schistose structure is complete.

Neither quartzite nor quartz schist is abundant in Connecticut. It caps Great Hill near Cobalt, where it is much like the numerous occurrences of quartz veins in the state. The exposures on Sharon Mountain and Cream Hill are of a massive granular rock, largely composed of quartz and feldspar. Areas of quartz schist occur in Tolland, Woodstock, Plainfield, Thompson, south of Bantam Lake in Morris, and small bands of the rock in a few other localities. The rock from Bolton was formerly quarried for flagstones, and glistening blocks from this locality may be seen in the

streets of our large cities. Quartz schist is suitable for whetstones, and was formerly quarried for this purpose at points in the eastern part of the state.

Slate is the metamorphosed equivalent of shales, or fine-grained clay rocks, which, in turn, are consolidated muds of various sorts. The chief constituents of clays and shales and other argillaceous rocks (besides a variable amount of kaolinite) are quartz and feldspar. In passing to a metamorphic stage the quartz fragments may remain as such, or they may be recrystallized, thus losing all trace of their origin. The feldspar alters to quartz and mica, and single feldspar fragments may be changed into a great number of crystals of quartz, mica, and feldspar. The fine quartz of slate is thus seen to be not the same as the original quartz grains in the mud or shale from which the slate developed. As in all cases of dynamic metamorphism, the mica crystals are developed in parallel position with long axes and cleavage in a common direction. It is due to this fact that slate splits so evenly. The mica crystals are usually too minute to be readily observed without a microscope, and are so massed as to produce merely a smooth surface. As might be expected, muds and shales are not made of pure quartz and feldspar, but contain many impurities; and, accordingly, many slates contain minerals like pyrite, etc., and only in exceptional places is the quality of the rock such as to render it commercially valuable. When a slate is further metamorphosed, but not to a point at which large crystals of mica are developed, it is termed *phyllite*. Such is the rock exposed in parts of Pomfret and along the shore at Woodmont.

Extreme metamorphism produces mica schist from slate and phyllite, and most of the Connecticut slate has reached that stage.

Schist.— Schists and gneisses are the two great classes of rocks produced by widespread, profound metamorphism. Practically all the crystallines of Connecticut fall into these groups. *Schist* is a term used to indicate structure, not

composition. The word implies nothing as to the minerals which compose a rock, but means that it has schistosity, and breaks readily and with a wavy surface along planes of foliation. Schists represent the extreme of metamorphic action, and may be derived from almost any sedimentary or igneous rock, or from almost any other metamorphic rock except marble.

Mica schist is a widespread formation in Connecticut, and is ordinarily developed from shale, sandstone, or conglomerate. As in the formation of quartz schist, mentioned above (page 62), the enormous pressure and heat of the zone of flowage granulates the quartz, and breaks up the feldspar into quartz and mica and other feldspar. Much mica is thus produced, and the mica increases in amount as the mashing and fracturing are more severe. Thus mica schist is a rock of schistose structure composed essentially of quartz, feldspar, and mica. While mica is not the most abundant of the three minerals, yet the size of its crystals and the fact that it forms a coat over the different layers make it the most conspicuous constituent. The feldspar present is usually albite, instead of the orthoclase which is more abundant in the original sediment. There are all stages in the formation of mica schist. Mica may be sparingly developed, and the original grains of the sandstone may play an important rôle; again, the rock may be in part slate and in part mica schist, or layers of schist may alternate with layers of altered sandstone; again, the rock may be typical mica schist with no trace of its former character. Most of the Connecticut mica schists have reached this advanced stage, and only rarely do structures occur which indicate the original form and composition. The size of the mica flakes or crystals varies from minute particles of muscovite, which form a coating over the schist plane, to large flakes an inch or more in diameter. Generally speaking, the larger the flakes the more severe the metamorphism. Mica schist rarely exhibits uniform parallel foliation, but irregular, wavy, and crumpled structures (See Pl. IX, Fig. 2). Moreover, a

mica schist formation may show great variety in composition; calcareous, argillaceous, ferruginous, and silicious beds may alternate or may form irregular inter-dovetailing lenses.

Because of the impurities in the original rock, mica schists often contain abundant minerals other than the main constituents. Garnet, fibrolite, cyanite, and staurolite occur in such quantities in the Connecticut schists that locally the rocks might be properly called garnet mica schist, cyanite mica schist, etc. In most cases, however, the development of such minerals on a large scale is local, and represents local variation in the composition of the original sediment. Mica schist which is slightly graphitic from the presence of organic material in the sediment also occurs in Connecticut.

Hornblende schist occurs in this state usually in belts interlaminated with mica schist or gneiss. It is greenish black in color, and consists of hornblende together with quartz, feldspar, biotite, and other minerals in smaller amount. Such a schist may result from the metamorphism of an impure dolomite, but is to be traced more commonly to some basic igneous rock, especially if the schist is quite free from minor impurities. One of the most common things in the rock floor of Connecticut is to find lenses, layers, streaks, and dikes of hornblende schist distributed without any apparent order within the larger areas of metamorphic rocks. In general they are ascribed to igneous intrusions at a date simultaneous with or prior to the last period of intense metamorphism.

Gneiss is a term used to designate a rock which possesses schistosity, but does not cleave into such thin laminæ, nor with such wavy, crumpled surfaces as schist. The amount of mica is proportionally smaller, and the quantity of feldspar is much greater than in schists. Gneiss appears as a much more massive rock than schist, and the layers into which it may be separated with ease are much thicker and

more uniform in character. The gneissoid structure, however, is produced in the zone of flowage in a manner identical with the schistose, and there is every gradation between schists and gneisses, as there is between gneisses and the unaltered rocks from which they may develop. Thus we may have schistose gneiss and gneissoid schist. Gneisses, like schists, receive special names from their characteristic mineral — mica gneiss, hornblende gneiss, etc.; or are named for the rock of which they are the metamorphosed equivalents — granite gneiss, diorite gneiss, etc.

Gneisses originally were sediments (sandstones and conglomerates), or igneous rocks of various types. In passing from a coarse sandstone to a mica gneiss, the individual quartz grains are destroyed, as is explained above under mica schist (page 64), and new quartz crystals are made. Feldspar breaks up into quartz, feldspar, and mica, and the impurities present form less abundant minerals. The larger pebbles in the sandstone are of course flattened and crushed; and, if metamorphism has not proceeded too far, remnants of the pebbles remain to tell the story of the origin of the gneiss. The gneisses of Connecticut have gone far beyond that point in development, and no traces of original pebbles have been observed.

The gneisses which originate from igneous rocks are much more common, and form larger areas. Here the process of metamorphism is chiefly one of rearrangement of mineral particles; the micas are drawn out into parallelism, as are also the other minerals; and new flattened micas are produced from feldspar. If the original rock was of simple composition, the gneiss will have practically the same mineral composition, the only noticeable difference being a greater abundance of mica, both muscovite and biotite. In case the igneous rock was porphyritic, the gneiss will also exhibit that texture, provided metamorphism has not advanced so far as completely to crush the phenocrysts. In such cases a gneiss produced from sedimentary conglomer-

PLATE XI.

FIG. 1. GNEISS FROM LEETE'S ISLAND QUARRY,
Showing gneissoid structure due to squeezing and stretching of granite.

FIG. 2. GRANITE FROM BOOTH'S QUARRY, WATERFORD,
Showing granite structure.

ates resembles superficially one produced from porphyritic granite (see Plate X).

The common types of gneiss in Connecticut are mica or granite gneiss,* and hornblende or diorite gneiss. The mica gneisses are ordinarily squeezed, mashed, and drawn out modifications of granite and related igneous types. Plate XI shows the contrast in structure between the gneiss and the unaltered granite. The production of gneiss is facilitated if granite intrusions occur in the region and thus furnish feldspar to be added to the rock during the process of alteration. The hot mass promotes the formation of solutions that carry abundant feldspathic material out of which feldspar can be made. Much of the beautiful banding in gneiss is produced, not by the common process of development of minerals under pressure, but by the intrusion of foreign material along the planes of schistosity, as is explained on pages 55 and 69. An outcrop of ordinary granite gneiss exhibits bands of granitic material separated by thin micaceous bands; but certain granite gneisses have, in addition to the foliation structure effected in the zone of flowage, a series of bands composed of light or dark colored rock which were originally no part of the constituents.

It ought, perhaps, to be stated that earlier geologists did not accept the theory here presented that gneisses are ordinarily squeezed and stretched granites. Gneiss was considered as modified sedimentary rock, and the gneissoid structure was believed to be equivalent to the planes of stratification in the original sediments. Furthermore, even granite areas were looked upon by some geologists as altered gneisses; that is, granites were supposed to have come from gneisses, and not gneisses from granites. Some gneisses are metamorphosed sedimentaries, most of them are altered igneous rocks, and no case is known where granites have originated from gneisses.

* This phrase, as used here, and as used by many writers, signifies a gneiss whose mineralogical composition is the same as that of granite, without regard to its origin. In Part II of this chapter the name "granite-gneiss" is applied to gneisses which are believed to be derived from granites.

Hornblende gneiss may develop, like hornblende schist, from impure limestone, but commonly represents a dark colored igneous rock, diorite, diabase, or some similar type. When in large masses, hornblende gneiss has a tendency to split into slabs with fairly smooth parallel faces.

Gneisses are not distinguished commercially from granites. Thus, the Monson "granite" and the Becket "granite", which are freely used in Connecticut buildings, are gneisses, as is the Glastonbury "granite", used for curbing in Hartford. The rock quarried along the Connecticut, from Middletown southward, and sold as granite, is likewise usually granite-gneiss. Parts of the Bristol and Collinsville "granites" are used for building, but much of the rock quarried comes from dark bands and lenses in a granite-gneiss formation, and is properly diorite-gneiss.

Igneous and Sedimentary Gneisses and Schists.— It has doubtless become evident to the reader that there is every gradation between the various gneisses and between the various schists, as well as between gneiss and schist, and unfortunately it often happens that these gradations occur in a single locality, and it is impossible to discriminate types and classify the rocks except in an arbitrary fashion. The difficulty is still greater when one attempts to trace the history of these rocks and to determine their original character. After a rock has become a gneiss or a schist, how is it possible to decide whether it was originally sedimentary or igneous, and what, therefore, was the condition of the country during the time of its formation? If any structures indicating deposition or any unchanged fragments of pebbles, etc., exist, then the sedimentary character is proved; but even here great care must be taken to distinguish between the structure of a crushed conglomerate and the structure produced in a rock which was metamorphosed, then injected with foreign material, and then crushed in a second metamorphism. When, however, all original structures are destroyed, and no localities can be found where

completely metamorphosed rock may be traced to less altered rock retaining some of the original character, no positive statement may be made. There is, however, one highly probable suggestion regarding such rocks. From their nature igneous rocks have a certain tendency toward uniform texture and composition, and freedom from important structure lines. When mashed by extreme metamorphism, they therefore tend to produce uniformly foliated, homogeneous schists and gneisses. Sedimentary strata, on the other hand, exhibit wide variations within a small space, and possess prominent structure lines. Their composition is variable, and an analysis of a sedimentary rock would be of very local application. A metamorphosed sediment is more apt to be heterogeneous, and to exhibit more marked banding and crumpling, and much greater variety of mineral constituents. However, this criterion must be applied with caution, and it is to be kept clearly in mind that some of the schists and gneisses of the state hold the secret of their origin fast; and, although we believe the rocks contain a record of their life within themselves, yet science has not advanced to a stage in which the symbols can always be deciphered.

Banding in Gneisses.— The structures which characterize gneisses have been brought about, as we have seen before, largely by pressure; and the difference in the appearance of the laminæ is due mainly to the greater or less amount of new mineral produced by metamorphic action. In this way the gneisses have assumed the banded or ribboned structure which may be scarcely noticeable or very conspicuous, depending upon contrasts in color and texture between the bands. There are, however, other ways in which this banded structure may be effected. In the cracks between the laminæ new minerals may be deposited from water solution, or the cracks may be filled by molten rock forced in from below. In this manner a banded structure would be produced that would closely resemble the structures due to lateral pressure. Furthermore, banding thus produced would bear much resemblance to original bedding

in sedimentary rocks, and must be carefully distinguished from it. When a rock mass is fissile, there is an excellent opportunity for the injection of igneous matter or for the introduction of material in solution; and, when the cracks are thus filled, the entire rock mass is firmly cemented together. Such a rock will have cleavage, but may show no evidence that it was once separated into distinct laminæ.

The best known of the Connecticut banded gneisses owe their structures largely to the fact that they have been injected and cemented after the development of schistosity; and, in fact, few gneisses within the state are free from material introduced along the planes of foliation. Plate XII shows a typical banded gneiss which has been injected during or after the time when the metamorphic structures were developed.

GRANITE AREAS.

Rocks of the parts of Connecticut covered by ancient crystallines have been so thoroughly metamorphosed that there is very little unaltered rock remaining. Granites which occur here are ordinarily gneissoid, like that in the Maromas quarry, and may be completely altered, or may show some of the original structures as at East Glastonbury and Derby. There are, however, some areas of granite which have been slightly or not at all affected by metamorphic processes, and which retain their original composition and texture. Such areas are small, rarely more than half a mile in diameter, and are distributed unevenly over the state, with, perhaps, a greater development toward the southeast.

The nature of these granite masses is not clear, but it is probable that they represent molten masses which were formed deep below the surface, and which are now exposed only because the overlying rocks have been eroded to a great depth. Many of these granite knobs are exposed to view along the coast, and here are located quarries which are of commercial importance. If the hypothesis above

PLATE XII.

BANDED STRUCTURE IN GNEISS, OTTAWA RIVER, NEAR MONTEBELLO.

From *Sixteenth Annual Report of U. S. Geological Survey.*

stated is correct, and if we imagine erosion to proceed much further, and perhaps an additional thousand feet of rock to be removed from the state, we should expect these granite knobs to appear in greater profusion, and the crystalline area, instead of being composed of gneisses and schists with a few small patches of granite, to be made up of granite with small bands of schists and gneisses between them. It is not supposed that these granite masses forced themselves into the rocks, lifting the strata above them, but that, as they invaded the overlying rocks, they quietly melted and assimilated them. Moreover, it is probable that the granites as they now exist are in large part made up of other rocks which have been molten and recrystallized. It is also probable that many of the granite areas now exposed are parts of chimneys or stocks of igneous rock, which reached entirely through the covering strata and poured out their molten mass as lava floods. All traces of such volcanic activity would have disappeared with the removal of the thousands of feet of rock which once covered the present surface. The age of these granite masses is unknown, but they are much younger than the surrounding gneisses and schists. Their age, relative to the metamorphics, is shown by the following facts:— they have not been subjected to the pressure which produces schistosity; they cut into and through the metamorphic rocks; and, occasionally, a fragment of schist or gneiss is included within the granite. For details regarding the structure and character of these granite areas the reader is referred to the discussion of the Stony Creek and other granite-gneisses of the shore line, and the Westerly granite (pages 147, 154).

PEGMATITES.

In addition to the granite masses mentioned above, there are found abundantly distributed over the state veins or dikes of coarse-grained rock composed largely of feldspar, quartz, and mica. These rocks resemble very coarse granite, and the individual crystals are commonly several inches,

and occasionally several feet, in diameter. One of the most interesting veins ever described occurs at Branchville, where single crystals were taken out which weighed from one hundred to two hundred pounds.

Such rock is called pegmatite. It has been termed "giant granite", but is not a true granite, and its origin is somewhat different from the ordinary igneous rock. It has been noticed that pegmatite occurs usually in veins from a few inches to one hundred feet or more in width and one hundred or more feet in length, though they may extend for thousands of feet. It is found that the composition of pegmatite generally varies in accordance with its distance from granite masses. Near the granite areas it closely resembles the true coarse-grained granite; farther away it is composed largely of quartz and feldspar, and at a still greater distance from the granite bosses pegmatite veins are apt to consist almost wholly of quartz. In this last case it is clear that the rock was formed like a quartz vein from aqueous solution; and, in order to account for the great variety shown in the same pegmatite vein, it is necessary to assume that pegmatite results either from aqueous solution, or from true igneous rock injection, or from the combination of the two. Water contained in rocks at high temperatures may carry large amounts of mineral matter in solution, and form what is practically a rock emulsion. The principle involved is stated by Van Hise, as follows:—"Under sufficient pressure and at a high temperature there are all gradations between heated waters containing material in solution and magma containing water in solution. In other words, under proper conditions, water and liquid rock are miscible in all proportions." Many pegmatite veins have crystallized from such aqueo-igneous masses, and are thus intermediate in character between veins and dikes, so that either of the two names may be applied to them.

These pegmatite veins, which are scattered so freely throughout the state, are the sources of quartz, feldspar, and mica of commercial value. In addition to the feldspar and quartz quarried from the pegmatites, as at South Glaston-

bury and New Milford, these veins have produced a variety of interesting and valuable minerals which have found their way to the museums of the world. In a vein of albitic pegmatite at Branchville, the following mineral species were found, several of them new to science:—albite, quartz, muscovite, microcline, damourite, spodumene (and its alteration products), apatite, microlite, columbite, garnet, tourmaline, staurolite, eosphorite, dickinsonite, triploidite, rhodochrosite, reddingite, amblygonite (hebronite), vivianite, lithiophilite, uraninite, fairfieldite, fillowite, chabazite, killinite, natrophilite, hureaulite.*

The Haddam Neck pegmatite is famous for its green and pink tourmalines, but produces also albite, microcline, green and pink apatite, red fluorite, beryl, quartz, cookeite, lilac lepidolite, greenish white muscovite, and a peculiar pink fibrous variety of the same mineral. Green fluor, microlite, columbite, also occur.†

Other pegmatite veins in the territory included in the towns of Middletown, Haddam, Chatham, Portland, and Glastonbury, have yielded sphalerite, gahnite, magnetite, chrysoberyl, bismutite, orthoclase (crystals), albite, oligoclase, beryl, iolite, garnet, epidote, tourmaline, muscovite (crystals), lepidolite, biotite, columbite, samarskite, monazite, triplite, torbernite, autunite, uraninite.

BASIC IGNEOUS ROCKS.

In the discussion of gneisses it was assumed that the typical Connecticut gneiss was a banded rock with a composition identical with granite. Some of the gneisses, however, are hornblendic, and have a composition which closely resembles that of diorite or gabbro. In addition to these hornblende gneisses there are areas of dark colored rock which have escaped the severer metamorphism and may be considered as distinct masses of basic rocks. As in the case of the granites, these are to be considered as bosses which

---

* *Am. Journal of Science*, series 3, vol. XVI, pp. 33-46, 114-123, 1878; vol. XVII, pp. 359-368, 1879; vol. XVIII, pp. 45-50, 1879; vol. XX, pp. 257-284, 1880; vol. XXXIX, pp. 201-216, 1890.

† *Mag. and Journ. Min. Soc.*, vol. XIII, pp. 97-121, May, 1902 (4 figs., 1 plate).

have invaded the surface rock from below and are now exposed by erosion. It is, of course, possible that these areas are the deep-seated representatives of ancient volcanoes, and that they were once connected with the surface and gave rise to lava flows of which no trace remains. Typical ancient basic rocks within the state are the gabbro-diorite in Preston, and the norite in Litchfield. (See pages 111, 152.)

Diabase Dikes.— The crystalline rocks of Connecticut are of very great age, and a long time elapsed between their formation and that of the diabase and basalt of the Connecticut Valley. There are, however, within the crystallines, a number of dikes of diabase which are believed to date from the time of the formation of the Connecticut sandstones, and which are thus very much more recent than the schists and gneisses which surround them. These dikes are shown on the geological map published by the State Survey. It is evident, from their structure and their relation to the surrounding rocks, that they have not been subjected to the movements in the earth's crust which have produced the schistosity so prevalent over the state. They are, however, intersected with numerous joints, and have been broken by the faults which have given character to the topography of central Connecticut. The rock composing these dikes is dark bluish in color, is massive, is finely crystalline in texture, and is in no way to be distinguished, superficially, from the material composing East and West Rocks at New Haven, and the Barn-door Hills in Granby.

TOPOGRAPHIC EXPRESSION OF THE CRYSTALLINE ROCKS.

A large part of the state is less than five hundred feet above the sea level. The elevation increases from the shore line toward the northwest, the highest point in the state being Bear Mountain, in Salisbury, which is 2,355 feet above the sea. A number of points in the western crystallines, especially about Norfolk and Litchfield, are between 1,000 and 1,500 feet in height, while the high points in the eastern crystallines rarely exceed 1,000 feet. The higher ridges

throughout the state are composed of schist, and not, as might be readily expected, of the harder gneisses. The ordinary schist is apparently very easily decomposed, and, when fissile, gives ready access to water which aids in its destruction. The gneisses, however, contain much greater quantities of feldspar, which is the most readily decomposed of all of the common minerals found in crystalline rocks. The result is that ridges like Box Mountain, in Bolton, and Satan's Kingdom, in New Hartford, although made of finely foliated schist, stand high above the gneisses which surround them. The chief topographic features of the area occupied by crystalline rocks are the elongated hills extending in a direction from a little east of north to a little west of south. This is the general direction of the foliation of all southern New England, and this structure has been a controlling factor in producing the form and direction of the hills. The main faults of the region are also northeast-southwest, and are an additional factor in determining the topographic relief. This direction is, of course, only general; there are many exceptions, and erosion has produced hills of a great variety of form.

Wherever quartz is abundant in the rock, erosion proceeds more slowly; and accordingly pegmatite dikes and quartz veins may stand out prominently. Certain hills in Plymouth, Barkhamsted, and New Hartford, and the White Rocks of Middletown owe their preservation to pegmatite veins. Lantern Hill, in North Stonington, is a quartz mass of unusual size. On a smaller scale, pegmatite and quartz veins occur as combs along the higher ridges. The prominent ridge of Great Hill, or Cobalt Mountain, on the boundary between Portland and Chatham, is capped by an extremely resistant quartzite.

The hills of the crystallines do not show rugged or precipitous outlines. This is due, not to the character of the rock, but to the fact that the entire region has been overridden by the continental glacier of the Glacial period, and the minor irregularities have been effaced. The direction of glacial motion was approximately from north to south, some-

what in line with the main rock structure, and has thus served to intensify the north-south course of the principal topographic features.

The general structure of Connecticut as a series of north-south ridges will be readily appreciated when the location of the railroad lines is observed. The Naugatuck Division and the Vermont Central, which run through the ancient crystallines throughout their extent in Connecticut, were inexpensive roads to build. There were no heavy grades, and no great fills or costly bridges to be made. The Hartford Division and the Northampton Division take nearly straight lines, and were practically built on a plane throughout their extent. If, on the other hand, we consider the Air Line Division, the Highland and Midland Divisions, and the Central New England, we see the great difficulties which are encountered in building a road from east to west. The Air Line from Middletown to East Thompson has heavy grades, and the entire road-bed is a series of expensive fills, deep cuts, and high bridges. The Highland Division from Willimantic to Danbury winds back and forth across the state, and goes many miles out of its way in order to escape the ridges in its natural path. These same features are exhibited by the Central New England, which crosses the Western Highland at an altitude of over 1,300 feet. Throughout its extent it is an almost continuous series of curves. If a road were to be built directly across the state, east and west, from Sharon to Putnam, or from Danbury to Norwich, the cost would be greater than commercial operations would justify, and the building would be little less difficult than railroad work in mountains. The financial history of these roads has been directly related to their geographical location, for less favorable location means increased cost in both construction and operation.

GEOLOGICAL HISTORY OF THE CONNECTICUT CRYSTALLINES.

The length of time since life first appeared on the earth is to be measured by tens of millions of years. The time

recorded in the series of fossiliferous strata has been divided for convenience into several eras, called Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Jurassic, Triassic, Cretaceous, Tertiary, Quaternary — each system being marked by characteristic fossils. Before these come the Archæan, showing no evidences of life, and the Algonkian, with only doubtful traces of life. An immensely long time it must have been before the earth was adapted for living forms. Fossils are the most readily applicable means of determining the age of rocks, and the only fossils found within the state are those of the Triassic sandstones — chiefly fishes, reptiles, and plants. There is, therefore, no formation within Connecticut older than the Triassic, whose age has been definitely determined by the examination of the rocks themselves. Their position in the time scale can be determined only by comparison with other regions where similar rocks are present in known relations. By combining such comparison with the study of the structure of the rocks themselves, it is found that the crystallines within the state have had a long and complicated geological history, beginning before the earliest fossiliferous strata were deposited.

Rocks older than the Cambrian exist in Connecticut, but we are ignorant of their origin and exact age. They may have been sediments containing fossils, or they may have been igneous masses. Whether they represent the Archæan or the Algonkian system, or both, is unknown. Their position and structure and texture are so altered by metamorphism that all evidences which might be used in determining their age have been destroyed. There is, however, little warrant for assuming in general that the gneisses and granites of Connecticut represent parts of the "original earth's crust." The Becket gneiss and certain other formations in Connecticut are believed to be pre-Cambrian, although without conclusive evidence.

A study of the Cambrian rocks of North America shows the distribution of land and water to have been very different from the present. There are some facts that suggest that Connecticut was under water, and that a land mass ex-

isted to the eastward beyond the present shore line. It has been fairly well demonstrated that a sea or bay of salt water stretched across western New England and up to the St. Lawrence. The extent of this Cambrian sea is unknown; but part of the marble of the Housatonic valley is believed to have been made from calcareous mud deposited at that time; and the quartzite at Poughquag, just west of the Connecticut border, is believed to be the metamorphic representative of a Cambrian sandstone.

During the Ordovician period the conditions for the deposition of sediments continued, and sandstones and shales and calcareous deposits were formed. The calcareous material is now represented by the upper part of the limestone of western Connecticut and Massachusetts, and the shales and sandstones are believed to have been the originals from which certain schists were developed by metamorphism. The accumulation of these sediments implies the wearing down of the adjacent lands, perhaps to a plain.

In western Connecticut no definite record is left of the long interval of time between the Ordovician and the Triassic. The absence of known Devonian and Carboniferous strata, and the facts which are known in regard to the geological history of eastern North America in general, suggest the belief that the state during these ages was part of a land mass bounded on the west by a salt-water sea and on the east by the ocean. Moreover, it is believed that Devonian time saw western New England molded into mountain ranges, and witnessed their disappearance into land of less relief. The inference that an area of dry land existed in western New England during Devonian time, rests upon the fact that the fossils found in Maine are unlike those of corresponding age found in New York, thus indicating the presence of an isthmus separating two water bodies in the northeastern United States. Then again, the sediments of Devonian age both east and west of Central New England show a retreating shore line, as if the land were rising along a northeast-southwest axis. The great thickness of Devonian sediments in the region to the west — 5,000 to 10,000

feet — indicates that the land area of New England constituted a mountain range comparable in height to the southern Appalachians and perhaps even rivaling the Alps.

Between the Ordovician and the Triassic occurred the universal metamorphism of the sedimentary deposits, with the intrusions of igneous rock and the formation of the numerous veins of quartz which form such characteristic features of the metamorphic crystallines. The portions of the intrusive masses now exposed to view cooled and crystallized beneath the earth's surface; but it is reasonable to assume that part of the molten rock reached the surface, and gave rise to volcanic phenomena, all traces of which have now disappeared. The date of these intrusions and details of their character are unknown. All that can safely be said is that they represent different periods of igneous activity and occurred between the Ordovician and the Triassic. Metamorphism of the pre-Triassic rocks occurred at some date or at several different dates later than the original deposition of the rocks. The exact time when these great changes took place cannot be stated, but the metamorphism in large part seems to have been associated with the mountain-making movements which were so marked near the close of the Carboniferous. A wide extent of territory in the eastern part of the United States was affected at this time, extending from the St. Lawrence to Alabama. Sediments which had been accumulating for ages were forced into smaller compass. Along the present Appalachians the rocks were folded into arches; and the more severe compression in New England resulted in profound alteration of the rocks and the production of slates, schists, and gneisses. The result is that no unchanged sediments of pre-Triassic age exist in Connecticut, but their metamorphosed equivalents are present everywhere. The igneous intrusions have likewise been forced in many places to develop schistosity and to take on gneissoid structure.

In brief, then, the history of Connecticut previous to the deposition of the Triassic materials seems to be as follows: The region was submerged beneath an extensive sea until

late Silurian times. During Devonian time mountain masses rose and disappeared. Throughout the Carboniferous era the state probably remained a land area, and near the close of this period the great metamorphic changes were produced.*

Indications of Paleozoic History in the Structure of the Crystallines.—As we have already seen, the crystalline rocks are chiefly schists and gneisses, and accordingly have structures indicating that they have been profoundly changed from their original sedimentary or igneous character. The original component minerals have been rearranged, stretched, and drawn out in lines; new minerals have been produced; parts have been fused and recrystallized. Instead of horizontal layers or uniform igneous masses, we find twisted and broken rock with layers, bands, and ribbon structures in every conceivable position. Moreover, this tangle of structure is further complicated by the presence of dikes, seams, and veins which have made their way into the rock at different stages of its history. In looking at this confused mass of rock which forms the Connecticut crystallines, it seems apparent that it has taken part in manifold changes which went on in the earth's crust for ages. This very complexity of structure and composition is an important aid in determining the relative age of the rocks, for it is evident that in general the oldest rocks must have been affected by the greatest number of disturbances, and accordingly the rocks of one age may exhibit structures not found in those of succeeding ages. In the absence of other criteria the geologist is forced to fall back upon this. These rocks are like a sheet of parchment on which writing after writing has been placed at different times by different hands, without at any time completely erasing the previous inscriptions. Little wonder that we have difficulty in deciphering the original writing!

* The outline of geological history given above is based on data published by the New York State Survey and the United States Geological Survey, and relates primarily to western Connecticut. Very little is known regarding the order of succession and age of the schists and gneisses of eastern Connecticut. Such conclusions as seem probable regarding their history are stated in connection with the descriptions of the formations in Part II of this chapter.

PLATE XIII.

UNCONFORMABLE CONTACT OF HARTLAND SCHIST AND TRIASSIC SANDSTONE, ROARING BROOK, SOUTHINGTON.

Photograph taken under direction of W. M. Davis for U. S. Geological Survey.

Such composition and structure as is described above can be produced only at very great depths in the earth (probably below 20,000 feet), where rocks are so deeply buried that, whatever the lateral stress, they will not adjust themselves by breaking, but by plastic deformation. It is therefore certain that, whatever the age of the crystallines, mountain ranges perhaps rivaling the Alps in height and ruggedness once occupied central Connecticut; and, when we examine the rocks of Satan's Kingdom, or the Quinnebaug Valley, or the Connecticut gorge below Middletown, or indeed any part of the area of crystalline rocks, we are studying the roots of lofty land masses composed of strata deposited during part or all of the Paleozoic era.

In a few localities these crystalline rocks are seen in contact with the Triassic sandstones. One such locality is the ravine of Roaring Brook, in Southington, two and one-half miles northwest of Plantsville.

The crystalline rocks exposed in the ravine of Roaring Brook belong to the Hartland (Hoosac) schist — a formation which occupies a large area in New England, and of which a special description is given on page 96. The schists are inclined at high angles, and their tops are irregularly eroded away. Lying directly upon the upturned edges of the schists are the brown sandstones and conglomerates of the Triassic, slightly tilted to the east, but otherwise unchanged since their original deposition and consolidation. The schists are the stump of a mountain range; the sandstones were deposited by water after the mountains had been reduced to a stump. Such a relation as is here exhibited between the schist and the sandstone constitutes an "unconformity", and means a lapse of time between two rock series. In the Roaring Brook section the lapse of time is from Silurian to Triassic — untold millions of years,— and the amount removed from the schists is unknown thousands of feet. Considered from this standpoint, the section exposed in the bank of Roaring Brook, as shown in Plate XIII, is one of the most impressive views within reach of the student of nature.

THE CRYSTALLINE ROCKS.

Part II.

SPECIAL DESCRIPTION OF THE CRYSTALLINE FORMATIONS.

INTRODUCTION.

It is hoped that the explanations given in Part I of this chapter are sufficient to enable the reader to appreciate the significance of the composition and texture of the chief rock types distributed over the state, as well as something of their origin and geological history. In the present part it is the intention to describe briefly the separate geological formations which constitute the ancient igneous and metamorphic rocks both on the east and the west side of the Triassic lowland.

Local geographic names have been applied to the formations, except in a few cases where rock of the same composition and stratigraphic position has been previously described in adjoining states. The formations along the Massachusetts line are usually continuous northward; but in some cases (for example, the Putnam gneiss) it seems wiser to retain the names used by the survey field parties than to use terms applied to similar formations outside the state. As the geological work in Connecticut progresses, it is quite probable that certain formations mapped and described separately will be found to be the equivalents of known deposits elsewhere, and that rocks which now seem entirely distinct may be found to be varieties of other formations. In any case it is to be expected that many changes in nomenclature will be required.

It is noticeable that the rock types represented in the Connecticut crystallines are prevailingly gneisses and

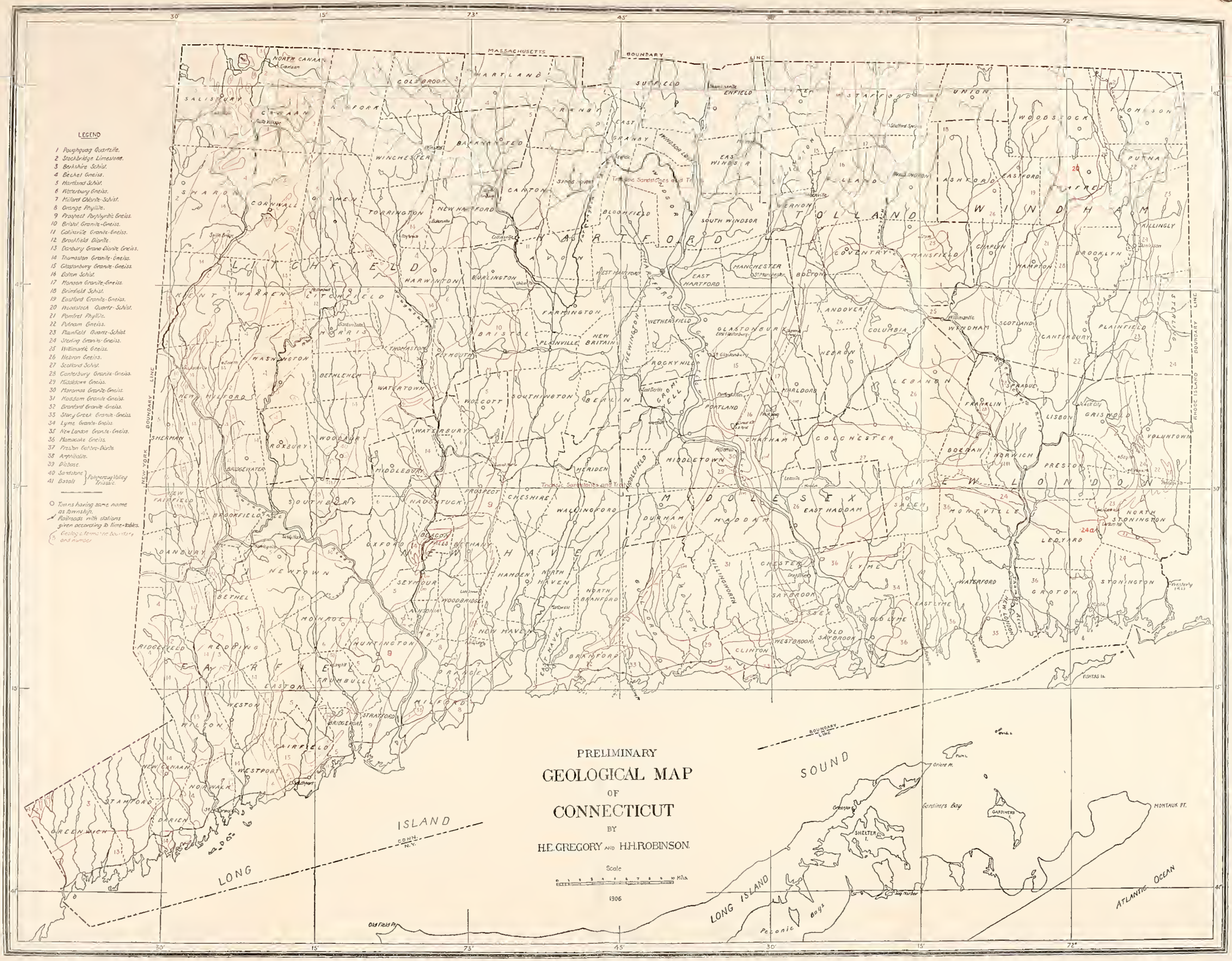
schists, as might be expected from the intense metamorphism to which they have been subjected. With the exception of pegmatite veins and small dikes of granite, and portions of the Preston gabbro, the Brookfield diorite, and some of the granite-gneiss areas, there are no rocks within the crystalline areas whose structure has not been markedly affected. It is customary to use the term "granite" for rocks consisting essentially of quartz and feldspar with mica or other dark mineral, as, for example, the "Westerly granite", the "Stony Creek granite", or the "Glastonbury granite". Strictly speaking, however, there are no areas of granite within the state large enough to be represented on the published geologic map. Granite, when the word is used strictly, is a rock massive in structure, with crystals of quartz, feldspar, and usually mica, all about of one size; its component crystals are not drawn out into lines, and foliation planes are not present in it. The development of foliation or schistosity by metamorphism produces a gneiss. A granite in which metamorphic action has developed a gneissoid structure, is a gneissoid granite, or, better, a granite-gneiss. The term "gneiss" implies nothing as to composition, but refers entirely to the surface appearance and structure of the rock. Thus we have Brookfield diorite-gneiss, Bristol granite-gneiss, etc. In this publication the word "gneiss" used alone is restricted to those formations possessing gneissoid structure which are believed to be sedimentary in origin (for example, the Putnam gneiss), or those whose origin is in doubt (for example, the Becket gneiss). In naming the rock types, field appearance and examination with a hand lens have, in the main, been relied upon; and it is altogether probable that laboratory study will result in a changed classification. Doubtless, also, rocks of unlike character will be found to have been placed in a single formation.

The age of the Connecticut crystalline rocks is uncertain, and whatever is said in this report as to their probable age is subject to radical revision. No formation within the crystalline area of the state has yielded direct evidence as to

its stratigraphic position. The Poughquag quartzite and the Stockbridge dolomite seem to be satisfactorily placed in the time scale by facts collected beyond the borders of Connecticut; and, if the Pomfret phyllite is identical with the fossiliferous phyllite at Worcester, a time horizon is established for the eastern part of the state. But, to say the least, the absence of fossils in these ancient rocks makes correlation difficult, and the results so far attained are unsatisfactory.

From what has been said it is evident that, from the standpoint of exact science, a satisfactory geological report and map of the Connecticut crystallines can not be made at the present time. The data are incomplete, and the interpretations are open to question. Under such circumstances it might be considered wise to delay the publication of a handbook until the entire region had been studied in detail by a group of trained specialists. It has seemed best, however, to present such facts as are available, and to put into the hands of those interested in Connecticut geology some work which will enable them to understand the main facts regarding the rock formations about them. This is deemed especially desirable since the complete study of the geological details may not be carried out for a number of years.

The data upon which the following descriptions and also the geological map are based, come from several sources, but chiefly from unpublished manuscripts written by officers of the United States Geological Survey and the Connecticut Geological and Natural History Survey. The region west of the 73d meridian has been surveyed by Professor W. H. Hobbs and assistants. The Litchfield Folio (containing a geologic map and descriptions of the area covered by the Cornwall, Winsted, Danbury, and Waterbury topographic sheets) is nearly ready for publication by the United States Geological survey. Credit should also be given to Professor J. D. Dana, who spent much time in the western part of the state, and to whom we owe our first accurate knowledge regarding the structure and relationship of the limestone areas of Connecticut and eastern New York.



PRELIMINARY
GEOLOGICAL MAP
OF
CONNECTICUT
BY
H.E. GREGORY AND H.H. ROBINSON
Scale
1906
LEGEND
1 Poughquag Quartzite.
2 Stockbridge Limestone.
3 Berkshire Schist.
4 Becket Gneiss.
5 Hartland Schist.
6 Waterbury Gneiss.
7 Milford Chlorite-Schist.
8 Orange Phyllite.
9 Prospect Porphyritic Gneiss.
10 Bristol Granite-Gneiss.
11 Collinsville Granite-Gneiss.
12 Brookfield Diorite.
13 Danbury Grano-Diorite Gneiss.
14 Thomaston Granite-Gneiss.
15 Glastonbury Granite-Gneiss.
16 Bolton Schist.
17 Monson Granite-Gneiss.
18 Brimfield Schist.
19 Eastford Granite-Gneiss.
20 Woodstock Quartz-Schist.
21 Pomfret Phyllite.
22 Putnam Gneiss.
23 Plainfield Quartz-Schist.
24 Sterling Granite-Gneiss.
25 Willimantic Gneiss.
26 Hebron Gneiss.
27 Scotland Schist.
28 Canterbury Granite-Gneiss.
29 Middletown Gneiss.
30 Maromas Granite-Gneiss.
31 Haddam Granite-Gneiss.
32 Branford Granite-Gneiss.
33 Stony Creek Granite-Gneiss.
34 Lyme Granite-Gneiss.
35 New London Granite-Gneiss.
36 Mamacoke Gneiss.
37 Preston Gabbro-Diorite.
38 Amphibolite.
39 Diabase.
40 Sandstone
41 Basalt
Pomperaug Valley Triassic.
Towns having same name as township.
Railroads with stations given according to time-tables.
MASSACHUSETTS BOUNDARY LINE
NEW YORK BOUNDARY LINE
RHODE ISLAND BOUNDARY LINE
LITCHFIELD
HARTFORD
TOLLAND
WINDHAM
FAIRFIELD
NEW HAVEN
MIDDLESEX
NEW LONDON
LONG ISLAND SOUND
ATLANTIC OCEAN
Gardiners Bay
Peconic Bays
MONTAUK PT.
Triassic Sandstones and Trap

The crystalline rocks bordering the Triassic north of a line through Higganum and Prospect have been studied by Professors Herbert E. Gregory and Lewis G. Westgate. The results of this work will appear in a report on the Farmington Quadrangle (consisting of the Granby, Meriden, Hartford, and Middletown sheets of the topographic atlas) to be issued by the United States Geological Survey. The eastern part of the state has been mapped only in a preliminary way under the auspices of the United States and the State Survey, by Professor Gregory and Dr. H. H. Robinson, assisted by Dr. C. H. Warren, Dr. W. E. Ford, and Dr. G. F. Loughlin.

Previous to the recent work carried on by the Federal and State Surveys no general work on the crystallines had been undertaken since Percival's "Geology of Connecticut" appeared in 1842. In that report important rock formations are distinguished and described, and marked off on a geological map. Percival's field observations were remarkably correct; but the nomenclature used by him, and his method of representing formations on the map, are such that it is practically impossible for the average reader to use his classic work intelligently.

With the exception of the smaller dikes, veins, etc., the formations described in this chapter are shown on the accompanying map (Pl. XIV). In making the geographic base for this map the Southern New England Telephone Company's map, on a scale of about three miles to the inch, was used. It has been simplified, however, by omitting roads and most of the names. Only a few of the rivers have been named, but others may be readily identified by reference to the topographic map of the state. Small circles give the location of villages or cities. Those villages or cities which have the same name as the town within which they are situated are not named. Stations on railroads are indicated by black dots, and have been taken from the railroad time tables. Boundaries of geologic formations are shown as red lines, and each formation is numbered in red, according to the legend at the left side of the map.

GEOLOGICAL FORMATIONS OF THE WESTERN HIGHLANDS.

With the exception of a small area of Triassic rocks in Woodbury and Southbury (see page 160), the entire western part of Connecticut, bounded by a line extending from New Haven to North Granby, is composed of ancient crystalline rocks. The distinct formations here represented are—the Becket gneiss, which is regarded as a pre-Cambrian complex equivalent to the Fordham gneiss in the vicinity of New York City; the Poughquag quartzite, of Cambrian age; the Stockbridge limestone, of Cambro-Ordovician age; the Berkshire (Hudson) schist, of Upper Ordovician age; and the Hartland (Hoosac) schist, probably of Silurian age. The Waterbury gneiss is Hartland schist modified by igneous injections. In addition to these there are igneous masses; namely, the Danbury granodiorite-gneiss, Brookfield diorite, Thomaston granite-gneiss, Collinsville granite-gneiss, Bristol granite-gneiss, Prospect porphyritic gneiss, Litchfield norite, areas of peridotite, and numerous amphibolite dikes and pegmatite veins. In the southeastern part of the district are found the Orange phyllite and the Milford chlorite schist.

Poughquag Quartzite§ [1] is distributed over the western part of the state with little order, and is restricted to isolated areas surrounded by other crystalline rocks. It occurs on Rattlesnake Hill in North Canaan, on the north and east sides of Barrack Hill, on the north flank of Cream Hill in Canaan, and on Sharon Mountain. It also occurs on the highlands west of Swift Bridge. Strips are found in Kent west of the Housatonic River, and likewise at South Kent. It occupies the south shore of Bantam Lake, extending from Little Mt. Tom eastward to the branch of the Naugatuck River. Small areas also appear west of Milford and west of Orange Center. Rock belonging to this formation

§ The descriptions of the formations west of the 73d meridian are based largely upon the work done by the United States Geological Survey under the direction of Professor W. H. Hobbs. Parts of this chapter are taken almost in their present form from the unpublished manuscript of the Litchfield Folio. This statement applies particularly to the descriptions of the Poughquag quartzite, Stockbridge dolomite, Berkshire schist, Brookfield diorite, Thomaston granite-gneiss, and Litchfield norite.

is found in northwestern Massachusetts, southern Vermont, and eastern New York, and is described in geological works as Cheshire quartzite. Similar rocks occur in a number of localities east of the Connecticut River, as will be described later; but whether or not they are of the same age is unknown.

The rock appears under two types. The first is a massive granular quartzite, composed largely of quartz and feldspar, the latter being microcline and orthoclase with a small amount of plagioclase. The feldspar may equal or even exceed the quartz in amount. Ordinarily mica is also present and is generally biotite. Where this rock has been exposed to the atmosphere for any length of time, it has weathered to a dull brown color, due to hydrated iron oxide. The schistose type, as found in Morris, is much more micaceous, and has a well developed schist structure. As seen in the field, it is quite unlike the granular rock of Sharon Mountain, but is believed to be a modification of the same formation.

Between Falls Village and Cornwall Hollow opportunity is offered for measuring the thickness of the Poughquag quartzite. Here the rock dips conformably beneath the Stockbridge limestone, and is believed to envelop an elongated dome of Becket gneiss. The measured thickness at this locality is between 700 and 800 feet. That the Poughquag quartzite is an altered sandstone is shown by the fact that often, even where it is most metamorphosed, fragments of the original sedimentary material occur in it. In certain places farther north the quartzite is so little changed that fossils have been found in it, thus determining its age as Upper Cambrian.

Stockbridge Limestone [2].— Metamorphosed dolomitic limestone is a prominent formation in the eastern United States. It is abundantly exposed in the upper Housatonic valley, and has received the general name of Stockbridge limestone, because of its occurrence at Stockbridge, Massachusetts. In Connecticut all the exposures of any importance are in the western and northwestern part of the state. A wide belt extends from Canaan Valley southwestward to

Sharon, and underlies a large portion of the towns of North Canaan, Canaan, and Salisbury. A narrow belt extends from Cornwall Bridge to Gaylordsville, forming the valley of the Housatonic River. A smaller belt, rarely attaining a mile in width, extends from New Preston through Marbledale, Northdale, New Milford, Brookfield, and Danbury, to West Redding. In the vicinity of Danbury this belt widens and sends an arm westward to the New York line. An area somewhat detached from the main belt occurs at Ridgefield, and a number of small limestone areas are found in other parts of the state, as at Winsted, Robertsville, East Hartland, Long Hill, and at a few places east of the Connecticut River. These small detached areas are identical in composition with the main masses of the Stockbridge limestone, and it may be that most of them are parts of one general formation, and owe their isolated position to accidental circumstances. There is, however, no direct proof of this. Beyond the borders of the state the Stockbridge limestone is found in more or less parallel belts which extend from Vermont to Georgia and include some of the most important building stones of the United States.

The Stockbridge limestone is one of the few geological formations in Connecticut possessing characteristics which enable the geologist to interpret without doubt its origin and geological history. The region occupied by this rock — the northwestern part of the state—has been made classic ground by Professor J. D. Dana. His papers on this region in the *American Journal of Science,* series 3, vols. IV, V, VI, and XXIX, show the care with which the outcrops were studied and the skill used in solving the difficult structural problems there presented. The work of Professor Hobbs in this region has added important new data, and the results of his study are to appear in the forthcoming Litchfield Folio, to be published by the United States Geological Survey. Professor Hobbs's acquaintance with the same formation in Massachusetts and in New York has enabled him to interpret the Connecticut structures and to add much new information.

The Stockbridge limestone is important economically, for in it occur the iron mines of Salisbury, Connecticut, and of Columbia and Dutchess counties, New York. The rock is burned for lime, and is an important building stone. The marble of the State Capitol at Hartford was quarried at Canaan, and the stone for the National Capitol at Washington was taken from the same belt farther north.

Because of its slight resistance to erosion the limestone usually constitutes valley areas. It is the natural channel of the Housatonic River; and, wherever the river has deserted the limestone bed, it has done so because of special structures in the rocks or because of the modifications produced by the ice sheet.

The Stockbridge limestone is a light gray marble of medium grain, having a thoroughly crystalline texture, and composed chiefly of calcite and dolomite. The relative proportions of calcite, dolomite, and impurities are shown by the following partial analyses made from specimens at Lime Rock and Sharon:—

	Lime Rock (1)	*Lime Rock* (2)	*Sharon* (1)	*Sharon* (2)
CaO	52.09	27.78	36.03	28.96
MgO	.47	16.93	17.76	18.54
SiO_2	4.11	4.21	4.00	9.98

The analysis of the rock at the Ashley Falls Marble Co., made by Messrs. Ricketts and Banks, gives the following results:—

CaO	30.03
MgO	21.57
CO_2	47.42
SiO_2	.28
Al_2O_3	.07
Fe_2O_3	.43
S	.03
Na_2O	.16
K_2O	.04
	100.03

This analysis shows that the Stockbridge formation at this locality is a typical dolomite, composed almost entirely of carbonates of lime and magnesia in proportions of 53.63 per cent. of the former and 45.07 per cent. of the latter.

A characteristic feature of the limestone is the presence of imbedded metamorphic minerals, some of them attaining large size, and all of them formed since the rock was deposited. The most distinctive of the minerals is a white pyroxene (diopside), which is known to quarry men as "Jason's teeth." It occurs usually in flat crystals, with characteristic octagonal cross-section. It frequently exhibits a silky surface owing to the development of tremolite, a variety of amphibole similar in composition to diopside. In the New Preston valley the tremolite is developed in plumose or fan-shaped groups of needles, which attain the dimensions of an inch or more. A yellowish brown mica — phlogopite —is also characteristic of dolomite, and occurs abundantly as minute scales. In places sericite is developed in such quantities as to alter the rock to a calcareous mica schist. In the Mt. Washington region the dolomite is occasionally graphitic. Chondrodite, pyrite, chalcopyrite, black calcite, clinochlore, and talc, also occur.

A modification of the Stockbridge limestone occurs in a number of localities, and has been named by W. H. Hobbs *canaanite.* It forms ridges of a few rods in width, but usually of considerable length, and is a white rock which weathers to a dark gray ragged or cellular surface. It is composed chiefly of diopside, and is believed to have been formed from the Stockbridge limestone by solution along the lines of fracture. A ridge of silicified dolomite extends between Falls Village and Canaan for a distance of about four miles. This ridge rises from the otherwise nearly level valley of the Housatonic, and its topographic form has apparently been determined by the fact that the Stockbridge limestone has been modified and hardened along this line. When the rock composing the ridge is examined, it is seen to have a framework consisting of interlacing veins of quartz. Within the meshes of this network is found the Stockbridge

limestone, showing an unusually coarse texture, in which are developed large crystals of tremolite and diopside. The tremolite occurs in distinct stars or wheels, the individual crystals being sometimes several inches in length. This silicified type of the Stockbridge limestone is believed to have been the result of crushing along the line of faulting. The rock was shattered, and later the fragments were cemented by water bearing silica in solution.

The lower part of the Stockbridge limestone was originally a calcareous mud deposited in shallow, widespread seas during Cambrian time. Part of it is of Lower Ordovician age, and there seems to have been no physical break between the Cambrian and Ordovician in this locality. The formation is so complicated by a series of close overturned folds, severe deformation, fracture, and faulting, that it is impossible to determine its thickness with accuracy; it is probable that its thickness varies within wide limits, and that in places it thins out until it entirely disappears. Along the border of the ancient land masses the formation is believed to have a thickness of five hundred feet or more.

Berkshire (Hudson) Schist [3] is a widespread formation in western Connecticut, which extends into Massachusetts and southward into New York. It may be roughly divided into two areas. The first occupies the extreme northwest corner of the state, including Bear Mountain, Indian Mountain, and a number of small hills which rise above the limestone of the Canaan-Salisbury district. The second area forms a long irregular line extending southwestward from Norfolk, and has its greatest and most characteristic development in Goshen, Cornwall, Warren, and Kent. An area also extends from Winsted northward to the state line. The New York City Folio contains a description of this rock at the southernmost extension of the belt. In the Salisbury region the formation is generally a gray or greenish gray muscovite-biotite schist, with rusty foliation planes, and usually closely folded. In places the rock has a greenish tinge, and passes into a chlorite schist or even a graphite schist toward the base of Mt. Washington. Porphyritic

minerals are imbedded in the schist, and their method of occurrence shows that they have been formed since the deposition and consolidation of the rock. These porphyritic crystals are usually feldspar and garnet, but staurolite, biotite, and tourmaline also occur. Fibrolite is sparingly present in the more metamorphosed phases of the rock, and red garnet and staurolite sometimes become so abundant as to form nearly all of the mass. The Berkshire schist in the eastern belt is usually less schistose, and its planes of foliation are less sharply folded. It is also much more modified by injections of granite and pegmatite; hence it often takes on a gneissoid appearance.

In the vicinity of the granite areas the schist assumes a knotty character, and the pegmatite veins are so abundant as to constitute a marked local variation. These pegmatite veins, from a few inches to a rod or more in width, are often visible at considerable distances, owing to the white appearance produced by the large amount of feldspar. The knots which form a characteristic feature of the eastern belt, vary from one-eighth to one-half inch in diameter. Usually they contain garnets, and often the garnet is a nucleus about which knots have developed. Except for the garnets, which are red, the knots are generally white or gray in color, and are sometimes connected with each other by threads or filaments of the same material. The knots are usually more resistant than the mass of rock in which they occur, and for that reason give the surface a peculiarly rough or cellular appearance. In addition to the garnets, these knots contain white pyroxene and feldspar, with smaller quantities of tremolite, sphene, biotite, apatite, magnetite, quartz, fibrolite, and epidote. In the vicinity of Norfolk the knots are mainly muscovite, quartz, and fibrolite.

Because of the large amount of granite and pegmatite injection the Berkshire schist may be readily mistaken for Becket gneiss, which it closely resembles in places. The gneiss, however, is much less micaceous, much less crumpled, and usually contains a greater amount of feldspar. The relation of the Berkshire schist to the rocks above and

below is well made out in localities in New York, Connecticut, and Massachusetts. Certain sections along the Central New England Railway show that it is conformable with the Stockbridge limestone; that it is above the Stockbridge is shown in certain localities near Salisbury, the north end of Barack M'teth, Turnip Rock, and Watawanchu Mountain. In a number of localities in and near New York City it is also found to overlie this limestone. The transition between the two is gradual. They are separated by a zone of calcareous schist and micaceous dolomite, ten to fifty feet in thickness, grading into the limestone below and the typical schist above.

The age of the Berkshire is Upper Ordovician (Hudson). It is found that the Berkshire schists of New York City connect stratigraphically with the slate and shale along the Hudson River to the north; and it is believed that slate, shale, and schist are but phases of the same rock. Where unmetamorphosed, it is typically shale; where metamorphosed to a slight degree, it is a slate; and where the metamorphism has proceeded to a very advanced stage, the rock becomes the typical Berkshire schist, with all traces of its former structure lost.

Becket Gneiss [4].— Large areas in western Massachusetts and Connecticut are occupied by a banded gray rock of fairly uniform appearance and much injected by basic and acid intrusions. This rock has been named Becket gneiss, from the town of Becket, Massachusetts, where it is well exposed and quarried for building stone. It forms a large part of the northern boundary of the state in Hartland, Colebrook, and Norfolk, beginning west of the East Branch of the Farmington River, and constitutes the plateau of western Hartland and Barkhamsted, where it is traversed by the West Branch of the Farmington River. Its greatest development in this region is in the towns of Winchester, Goshen, Sharon, and Cornwall. Considerable areas are found in Warren, Washington, and New Milford; and a series of areas extends, with some interruptions, to Norwalk. Small detached areas occur elsewhere. Farther to the

southwest, the rock appears as the Fordham gneiss on the maps of the New York City Folio.

Where typically developed, as at New Hartford, the Becket gneiss is light gray in color, of firm texture, and has a uniform banded structure produced by the segregation of biotite along certain planes, so that layers composed chiefly of feldspar and quartz alternate with those rich in biotite. These bands are usually less than an inch in width, and show great variation in tones of gray, depending on the abundance and character of the mica present. In places the gneiss is highly quartzose and granular; elsewhere, as in parts of West Hartland, the gneissoid structure is so poorly developed that the rock might be called a granite, composed of feldspar, quartz, muscovite, biotite, and garnet. Where the gneissoid bands are very thin, the rock grades into a feldspathic schist, and in places is scarcely distinguishable from parts of the Hoosac formation. Microscopic examination shows the Becket gneiss to be composed of feldspar, quartz, and biotite, with smaller amounts of garnet, titanite, apatite, magnetite, and zircon. Muscovite is present in small amounts, and in some localities becomes an important constituent. Hornblende rarely occurs. The most abundant feldspar is microcline, but orthoclase is common, and there is also present a plagioclase which is usually albite.

Considered as a formation, the Becket does not appear as the uniform gray, banded rock described above, for it includes many schistose phases and also the ancient intrusions which have had the gneissoid structure developed in them by metamorphism. Thin granitoid layers, sometimes almost white from the absence of biotite, are interbedded with the gneiss, while layers of hornblendic gneiss and schist frequently occur. These parallel, interbedded layers, granitic, micaceous, and hornblendic, vary in width from a few inches to over one hundred feet, and, at irregular intervals, are intercalated with the more typical portions of the Becket, usually constituting elongated lenses rather than definite beds of great length. Included within this formation are many quartz veins, and also veins of pegmatite composed

of coarsely crystalline feldspar, quartz, biotite, and muscovite in variable proportions. Rarely magnetite, beryl, and tourmaline are found in them. These pegmatite bands occur parallel with the main direction of the schistosity of the gneiss, or cut across the beds at various angles. They are seldom over 25 feet in width, and do not usually extend continuously for more than a few hundred feet. In a few places the Becket gneiss includes a coarse granite-gneiss with a prominent red feldspar. Such areas are found upon Cream Hill in Cornwall and on the slope to the west of Cornwall Bridge. Smaller areas are found north of Torrington, near Daytonville, and in New Hartford.

It is not possible to state definitely the age, the thickness, or the original nature of the Becket gneiss. It is probably the oldest formation in the region, since it is cut by all the intrusions, and has been shown by Emerson to underlie unconformably the Hoosac (Hartland) schist. It is ascribed with some hesitancy to pre-Cambrian time. There are no criteria for determining the original thickness of the Becket gneiss. It contains no characteristic beds which may be used as standards of reference. Its original thickness has doubtless been increased and repeated many fold by folding and compression, and there is evidence that a large but unknown amount of faulting has further modified the initial thickness. The former nature of the beds is equally uncertain. It seems probable that they represent an area of granite which has been injected by various igneous masses at different times and subjected to intense metamorphism while yet deeply buried within the earth. On this hypothesis the more granitoid phases are most like the original rock, and the schistose varieties are most metamorphosed. The hornblendic and granitic beds were intruded before or during the chief metamorphic movement, and owe their position and alignment to the forces that produced the main foliation. Veins of quartz and pegmatite were intruded after most of the metamorphism had taken place, and certain intrusions indicate even a later stage of igneous activity.

Whether the rock now represented by the Becket gneiss was formerly igneous or sedimentary, its original attitude and texture have been destroyed by movements in the earth's crust. The number and sequence of these movements is unknown, but sufficient deformation has taken place to produce throughout the entire formation a distinct foliation which is seen in the field as well as in hand specimens. The microscope shows that the quartz and mica have identical orientation, thus producing parting planes; also that the crystals composing the rock are often crushed and broken into lines, and that other structures characteristic of metamorphic rocks are present. Most of the rocks intruded into the Becket have likewise had their identity destroyed by general metamorphism. The diorites and gabbros have become hornblende schist or impure soapstone and asbestus, and only rarely, as at New Hartford railroad station, does an amphibolite show clearly its dike-like habit. The forces which produced the compression in this area acted principally from the southeast, thus causing planes of schistosity which extend in a northeast direction, and which are usually so steeply inclined that only the edges of the layers are exposed to view.

Hartland (Hoosac) Schist [5].— The Hartland (Hoosac) schist in Connecticut is the southern continuation of large areas of rock on Hoosac Mountain and in adjacent regions of Massachusetts. Where it enters the state, it is a belt of schist six miles wide, forming a plateau between the Farmington River and the western border of the Triassic, in Hartland, Barkhamsted, Granby, and Canton. South of the Farmington River it includes Satan's Kingdom and other highlands in New Hartford and Burlington, extends in elevated ridges and hills to Plymouth, and forms the Wolcott plateau. This formation continues southwestward as a narrow ridge, through Prospect, Bethany, Beacon Falls, Naugatuck, Oxford, and Seymour. It forms Beacon Hill, Andrews Hill, Huntington Hill, and the highlands west of Seymour village. A second area extends almost uninterruptedly as a belt three to six miles wide from near East

Litchfield to beyond Hawleyville. It forms the bed rock over large parts of Litchfield, Bethlehem, Washington, Roxbury, Southbury, and Bridgewater. The rock is everywhere mica schist of definable character, but exhibits great variation in texture, composition, and field appearance. Its aspect has been rendered still more complicated by the intrusion of igneous rock on a large and a small scale. Where least affected by intrusion, the rock appears as a highly fissile schist. The planes of schistosity are determined by plates of muscovite and biotite in overlapping crystals or irregular intergrowth. The mica varies in size from flakes an inch or more in diameter to minute films or threads visible only under the microscope. In color it ranges from clear metallic muscovite in West Granby, to a black biotite mixed with graphite farther to the south. Sericite and chlorite often replace biotite. Garnets are almost constantly present, and locally occur in such quantities as to be of commercial value. Garnet crystals of the size of walnuts are occasionally observed in Roxbury and Washington. The local development of unusual quantities of this mineral in large crystals is believed to be due to local deformation along special structural lines. Staurolite crystals from an inch to two inches in length are also locally developed. Cyanite is scattered sparingly throughout the entire extent of the schist, and in places becomes the chief constituent of the rock. Next to mica and garnet, cyanite is the leading metamorphic mineral in the Hartland (Hoosac) schist, and occasionally occurs in Litchfield, New Hartford, and Barkhamsted, in crystals from two to three inches long. In places the porphyritic structure is developed, and large crystals of feldspar are closely wrapped about with films of mica. As may be seen in the railroad cut at Satan's Kingdom, the Hartland (Hoosac) schist is almost never free from quartzose and feldspathic impregnation, but its amount and character vary widely. Such impregnation may be caused by granitic injection, in which case the rock closely resembles a biotite gneiss. The granite may occur along the plains of foliation, as bands and lenses from a few inches to

one hundred feet in length. Basic intrusions are found throughout the schist, and in places, as in southeast Wolcott, form prominent beds over wide areas. Amphibolite is the common dark colored intrusive, and has the gneissoid and schistose characters of similar intrusions in the Becket gneiss. Pyroxene schists and eclogite schists also occur as lenses, layers, and areas of irregular shape. Granites, usually with pink feldspar, and pegmatites, and rarely quartz veins, are the latest intrusions in the Hartland, and are arranged either parallel to the planes of foliation or cutting across them. Part, at least, of the pegmatites are later than the metamorphic structures. The aggregate number of the later granitic and pegmatitic intrusions is very large. In the railroad cut on the south side of the gorge at Satan's Kingdom, where the rock wall is exposed for 1,700 feet, there are seven granitic layers with a combined width of 860 feet, besides several smaller seams. The granitic and pegmatitic intrusions are so numerous and of so small size that no attempt has been made to map them individually. One marked feature of the granitic and pegmatitic intrusions is the increase in the amount of cyanite, staurolite, and garnet near them. Occasionally there are nests and stringers of beautiful cyanite crystals within the pegmatite itself.

No fossils have been found in the Hartland (Hoosac) schist, and there is much uncertainty regarding its stratigraphic position. Whatever evidence exists on this point comes from a study of areas west and north of the state. Professors Emerson and Wolff conclude that the Hoosac schist is equivalent to the Berkshire schist of western Massachusetts, and this in turn has been shown to be equivalent to the Hudson schist of New York; that is, of Upper Ordovician age. It is, however, entirely possible that the Hartland is a later formation than the Hudson schist, and it is perhaps of Silurian age. Until fossils are found, or reliable criteria are discovered which suffice to show the relative order of superposition, the place of the Hartland schist in the geological column can not be determined.

It is probable that the Hartland (Hoosac) schist was originally a series of sedimentary beds, largely argillaceous sandstones and shales, with occasional calcareous and highly silicious strata, perhaps like the sedimentaries of the Triassic areas. The great variety now exhibited in the schists is partly due to variation in the original sediments, and partly to the unequal amount of metamorphism and injection that has taken place as a result of pressure, heat, etc. The changes produced in this formation by metamorphism since deposition are very great. The quartz and calcite have been recrystallized, and some of the limestone has been further changed to hornblende schist. Much of the feldspar has been broken up into feldspar, quartz, and mica; and many secondary feldspar crystals have been formed and afterwards flattened and elongated. The argillaceous beds have been altered chiefly by growth of new mica, and this has progressed so far that schists are much more common than rocks with flaggy or slaty structure. Schistosity has been produced by a flattening of all crystals, and by the production of new flat minerals, especially biotite, muscovite, sericite, chlorite, and cyanite, arranged parallel with each other, thus producing planes of easy parting. The micas are often wrapped around larger crystals of feldspar, quartz, and garnet. Metamorphism has progressed so far that all the original structures have been destroyed and new ones developed. The schist beds show great profusion of complicated folds and crumplings* and minor faults which have no fixed relation to the original planes of sedimentation.

The Hartland (Hoosac) schist is a resistant rock and weathers slowly because of the relatively small amount of feldspar. Where the disintegration has proceeded far there remains a soil composed chiefly of mica and quartz grains. The planes of schistosity usually dip at high angles, so that a surface exposure exhibits only the edges of the schist planes, and a railroad or river section shows the layers to stand nearly on end. It is not possible to determine the

* See Plate IX, Fig. 2.

thickness of the schist even approximately, for there is no way to ascertain the amount of increase due to the repetition of beds by crumpling and faulting. This formation has been cut off by a fault on the east, while much has been removed by erosion on the west.

Waterbury Gneiss [6] is not a distinct geological formation, but a complex of schists, which have been intricately injected with granite and pegmatite and occasionally amphibolite, in endless variety, without regular arrangement. It is believed that the areas marked Waterbury gneiss in the towns of Naugatuck, Waterbury, Torrington, Middlebury, and elsewhere, were originally Hartland (Hoosac) schist, and that granitic intrusions and quartz veins have impregnated them to such an extent that their original condition is almost entirely concealed.

Milford Chlorite Schist [7].— With the exception of a small area about Woodmont, the Milford chlorite schist occupies the shore line from Stratford to West Haven, as a belt rarely over two miles in width. It forms a narrow band adjoining the Triassic in the town of Orange, and dies out in the Woodbridge Hills west of Dawson Lake. The prevailing rock is a greenish chlorite schist, varying in thickness and hardness. In places it is evenly foliated, elsewhere highly contorted, and presents on surface exposures a series of broken anticlines and synclines. Quartz is an important constituent of the formation, and occurs in seams, lenses, and veins; it is also distributed in minute particles throughout the schist. Small bands of impure serpentine are found in it at several localities. In places the rock is massive, with the schistose structure hardly at all developed. Where it assumes this character it consists largely of hornblende and feldspar and constitutes the labradioryte of Dana. Occasionally this more massive variety is porphyritic from the presence of crystals of labradorite. In the vicinity of the Maltby Lakes a typical schistose rock occurs, and with it a considerable amount of impure serpentine — a dark colored rock, clouded and banded with patches of green, yellowish white, and black. From a quarry formerly located at this place

large slabs were obtained and polished, specimens of which may be seen in the geological collections in Yale University. A similar quarry of "verd-antique marble," discovered two miles east of Milford in 1811, was worked for a short time. This "marble" differs in appearance from the Maltby Lake rock in being bluish, rather than yellowish green. In the quartz veins associated with the chlorite schist crystals of chalcopyrite have been found. The Milford chlorite schist is believed to have been originally a diorite or similar basic igneous rock with intrusions in the form of dikes. The entire mass was afterwards much metamorphosed, drawn out into lines, and a definite schistose structure given to it.

Orange Phyllite [8].— The Orange phyllite extends from Stratford to the east line of Bethany, forming the banks of the Housatonic River from near Derby to the Sound. In Orange and Woodbridge the formation attains a width of about six miles, and it dies out in the trap ridges near the southern line of Prospect. A small area occurs along the shore at Woodmont. The rock is a slate or phyllite, highly fissile, sericitic, and usually dotted with minute garnets. Toward the west it is much more micaceous, in places approaching mica schist in texture, and is also frequently feldspathic. The latter feature is so prominent in certain localities that the rock might well constitute a separate formation. This micaceous phase of the otherwise argillaceous phyllite forms a belt between the typical argillaceous rock and the Prospect gneiss, and is believed to be a contact zone in which the phyllite has been modified by injection of the igneous mass. In structure the Orange phyllite is commonly minutely folded and contorted, and is so traversed by joints that it breaks readily into small polygonal fragments. Generally it readily decomposes and forms a dark clayey loam. Quartz veins occur frequently; and large and small chunks, lenses, and fragments of quartz are almost universally found in the formation.

Beds of impure limestone or marble are interstratified with the more argillaceous beds in a number of places. An abandoned lime-kiln is located on Sargent's River, north of

Westville, where the calcareous rock stands at a high angle between layers of phyllite (hydromica schist of Dana). Minute cubes of pyrite and much mica in fine scales are found associated with calcite. The presence of pyrite together with calcite is favorable for rapid weathering, and the ledges are covered with a thick brown crust. The impurities in the limestone, especially the mica, render it unfit for the production of lime, and the quarry was therefore abandoned. Orange phyllite is believed to have been originally a shale, more or less calcareous. It has since been metamorphosed, but not to such an extent as to be converted into mica schist.

Prospect Porphyritic Gneiss [9].— The Prospect gneiss occupies a triangular area in the towns of Prospect, Cheshire, and Southington, limited eastward by the Triassic strata, and extending south as a belt of varying width through Derby, Huntington, and Stratford. The rock is well exposed along the line of the Middletown and Waterbury railway, near Prospect and Summit stations. Here its characteristics are well developed, and from this region have doubtless come many of the bowlders of "mosaic" gneiss distributed over the region between Cheshire and Bridgeport. Typical outcrops also occur along the Housatonic River at Shelton.

The formation consists of a light gray porphyritic gneiss. The gneissoid appearance is produced by bands of granular quartz and feldspar interbedded with layers composed chiefly of biotite. Muscovite, garnet, chlorite, zircon, and titanite occur with the more abundant constituents. Within the ground-mass formed of these minerals there are set larger crystals of feldspar, mostly orthoclase, white or pink in color, thus giving the gneiss a porphyritic structure. These phenocrysts vary from one-sixteenth of an inch to three inches in their longest diameter, are quite fresh and regular, and in nearly all cases show twinning structure. Besides the typical coarse porphyritic gneiss, there occur in this formation small areas of porphyritic granite with inconspicuous gneissoid development, and narrow bands of mica schist distributed unevenly and not attaining the prominence which these beds have in the Becket gneiss. Pegma-

tite is found but rarely. At its extreme northern limit the Prospect gneiss is prevailingly less porphyritic and more quartzose, and contains areas of intrusive basic rocks.

This formation is believed to have been originally a mass of porphyritic granite intruded into the Hartland (Hoosac) schist. No contacts are visible, however, and direct proof of the date and nature of the intrusion is not at hand. Metamorphic processes have converted the rock into a gneiss with planes of schistosity whose strike averages about N.25°E. The marked characters of the original rock were such that the changes induced by folding and metamorphic action are readily traced. The phenocrysts of orthoclase were originally set at various angles in a granite groundmass. Some of these were so oriented as to resist effectively the metamorphic forces, and consequently they remain in their original condition, with the exception that they are somewhat flattened, crushed at the ends, and converted into microcline. The phenocrysts less favorably situated have been squeezed, broken, and rotated into parallelism with the planes of schistosity. In many instances the original crystal is represented by lenses and eyes of granular feldspar and quartz, and in extreme cases all traces of the crystal are lost in the general gneissoid structure of the ground-mass. Besides the granular bands produced by metamorphism of the quartz and feldspar of the original rock, much new biotite and garnet have been formed, and, in less amounts, the other minerals mentioned above. The mica is seen to wrap about the feldspar phenocrysts and to be closely adjusted to it. Because of the unequal amount of metamorphism the Prospect gneiss varies from porphyritic granite, through gneiss containing flattened nodules, to a rock in which so great crushing and rearrangement have taken place that it has become a feldspathic mica schist.

Prospect gneiss is not porphyritic throughout its whole extent. Its western extension assumes a typical granitic texture, and in places its gneissoid structure is not well developed. In fact, the differences between this gneiss and the

Danbury granodiorite-gneiss are not always evident, and it may be that the two formations are parts of one granitic intrusion.

Bristol Granite-gneiss [10].— This formation occupies an area of about fifteen square miles, mostly in the town of Bristol, from which it derives its name. Topographically it forms a basin surrounded by a rim of Hartland (Hoosac) schist, and seems to owe its relatively rapid erosion to the presence of iron compounds and a great amount of feldspar as compared with the schists. The formation consists of granite of varying texture and color, of gneisses and schists derived from the granite, and of hornblende gneiss and hornblende schist. Pegmatite in veins and lenses of considerable size occurs in the eastern part of the city of Bristol.

The typical Bristol granite-gneiss is light gray, with gneissoid structure more or less developed by the presence of layers of biotite; the more schistose layers have muscovite. Quartz, orthoclase, some oligoclase, andesine, and biotite are the chief components of the rock. Garnet is nearly always present, and in places rises to the rank of a principal mineral. Chlorite, zircon, hornblende, also muscovite in the more schistose layers, are present as accessory minerals. Chalcopyrite is scattered through the rock, and is accumulated in little bunches of crystals. It is probable that the copper minerals are from the same source as the copper found in small amounts along the western border of the Triassic, and formerly mined at a point three miles northeast of Bristol.

A noticeable feature of the granite-gneiss is the presence of rounded and lens-shaped eyes, made up of a zone of white, granular quartz-feldspar aggregate, inside which is a dark spot composed largely of garnet and chlorite. The iron compounds have gone into the centers by segregation. These eyes are from one-sixteenth of an inch to two inches in diameter, but within the granite are areas, ten to thirty feet in diameter, of black rock composed of hornblende, chlorite, and garnet, which may have had the same origin as the smaller spots. These larger chunks were evidently

formed before regional metamorphism took place, for the minerals of the gneiss have adjusted themselves to them by bending and shearing.

The heavy cover of drift and the prevalent metamorphism make it difficult to determine the range of variation within the rock and its relation to the Hartland (Hoosac) schist. The formation is believed to be intrusive, as indicated by the fact that the schist dips away from the granite and seems to be controlled by it in its metamorphism. Parts of the granite-gneiss are traced with some uncertainty into the schists. The latter near the contact are highly metamorphosed into filmy sericitic varieties, and contain an abundance of mica and tourmaline; the granite shows local variations into hornblende gneiss, occasionally containing epidote, all along the east and southwest border. Aplites and tourmaline-bearing pegmatites also occur near the border. The Bristol granite-gneiss is believed to have been an intruded mass within which basic areas formed by segregation, especially about the edges. The surrounding sedimentary rock suffered contact metamorphism; at a later period granite and sediments alike were affected by regional metamorphism produced by a series of earth movements. The granite suffered great changes during the metamorphism of the rock. Quartz was broken and recemented; feldspar developed into new crystals of feldspar, mica, and quartz; biotite and hornblende changed in part into chlorite. These minerals crystallized parallel to the planes of differential movement, thus producing schists and gneisses which vary in amount of schistosity from almost unaltered granite to extremely finely divided schists bearing little resemblance to the original rock.

Collinsville Granite-gneiss [11].— Within the towns of Avon and Canton is an area of granite-gneiss. It forms the flattened ridge between the Farmington River and Roaring Brook, and also the prominent peak of Mt. Horr north of Canton station. At Collinsville this formation is particularly well exposed, and has received its name from that village. As seen in the ledge the rock exhibits usually a

banded gneissic structure, but it is unevenly and irregularly developed. Two types appear intermingled without order:—a light gray, heavy-bedded rock, grading into massive granite; and a very dark gray to black variety which grades by imperceptible stages into even-banded hornblende gneiss and rarely into schistose phases. The light colored variety is finely crystalline, and, where it is distinctly banded, shows black lines of biotite running through the rock, as well as patches arranged along planes of schistosity or evenly distributed through the mass. Where minutely injected, the rock appears coarsely crystalline, often with pink feldspars. It consists of feldspar, largely orthoclase but with some microcline and oligoclase, quartz in irregular grains, biotite in shreds or groups of plates sometimes radially arranged. Besides these essential constituents, hornblende and garnet and muscovite are usually present in small amount, and zircon, titanite, and magnetite have been observed. Chlorite occurs in the more schistose forms. The darker varieties of gneiss are produced by the greater development of biotite in bands and patches, and the rock splits readily into even slabs from one inch to ten inches thick.

The areas of hornblendic gneiss vary in size from mere bands and lenses to masses several hundred feet in diameter. The schistosity is well developed, and the faces of layers show mats made of intertwined hornblende and biotite. The rock consists essentially of hornblende with some quartz and feldspar. Epidote, garnet, biotite, zoisite, and chlorite occur in greater or less abundance in nearly all the hornblende rocks. Magnetite and augite have also been observed. Some of the hornblende rocks near the border are abundantly garnetiferous.

Dikes and veins of fine-grained granite and coarser pegmatite occur in the Collinsville granite-gneiss. These vary in width from one-sixteenth of an inch to a hundred feet, and in places are abundant. In Collinsville, near the Central New England station, six such dikes may be seen in an outcrop 250 feet long. Some of these pegmatites and some quartz seams

follow the schistose structure in its minutest folds; but for the most part the pegmatite and granite intrusions are clearly younger than the gneiss, for they cut across it at various angles and send off stringers and dikes into the surrounding rock. These granitic intrusions are made up of feldspar, quartz, and biotite, with some rutile, less muscovite and chlorite, and smaller amounts of garnet and magnetite.

The Collinsville granite-gneiss is believed to be a mass intruded in the Hartland (Hoosac) schist, and to have gone through about the same changes as have been already explained for the Bristol granite-gneiss. The contact has not been observed; and, even if exposed, it would scarcely be recognizable, owing to the minor intrusions and the metamorphism. The exposures in the Farmington River at Unionville show schist wrapping closely around gneissoid granite, with marked differences in attitude and composition; and in general the schist is seen to have adjusted itself to the granite and to dip away from it. Somewhat greater metamorphism of the Hartland (Hoosac) is noticed near the border of the granite. Much folding and minor faulting has taken place in the granite-gneiss, and buckling and crumpling are observed, particularly along the Farmington River. The axes of the larger folds dip under the schist. Metamorphism has produced gneissoid structure in the granite by rearrangement of the original minerals and by the production of much new biotite. The more dioritic facies of the original rock is represented now by hornblende gneiss, and more intense metamorphism in parts has produced schists from these two types. Most of the original structure has been destroyed. Hornblende and plagioclase are so abundant in parts of the Collinsville granite-gneiss that the whole formation might be called a granodiorite-gneiss.

Brookfield Diorite [12].— An area of diorite extends from near New Milford southward to Brookfield Center with a length of about eight miles and a width of one mile. At Hawleyville occurs another area of irregular outline, and

a still larger area is found in Litchfield and Morris, northwest of Bantam Lake. Outcrops of amphibolite may be included in the Brookfield, as the two are difficult to distinguish in the field.

The diorite is usually massive, but shows also gneissoid and even schistose phases. Both light and dark types are present in this formation, the former containing much quartz, and in extreme cases containing no dark mineral except biotite. The darker variety shows an almost complete absence of quartz and the presence of dark hornblende or a mixture of hornblende and biotite. Phenocrysts of feldspar assume a prominent rôle in the darker rocks, giving a porphyritic appearance.

While the rock in general resembles in appearance a porphyritic granite, schistosity has been developed, especially around the borders of the mass, and injection has produced a banded effect, generally accompanied by the production of new minerals, especially sericite, garnet, and staurolite.

The Brookfield diorite is an igneous mass intruded into the quartzite and schists of this region, as is shown by the facts that the Poughquag quartzite has been intricately injected, and that fragments of the surrounding gneiss are found included in the diorite.

Danbury Granodiorite-gneiss* [13].—This rock has an extensive development in western Connecticut. The largest area extends from near Birmingham to Bethel, and from Sandy Hook nearly to Easton. Belts extend through New Fairfield, Weston, Westport, and Fairfield, and along the coast line for most of the distance between Darien and the New York boundary. Still other small areas occur as shown on the geological map.

The rock presents two important facies — a biotite granite, and a diorite in which hornblende becomes an important constituent and quartz is less prominent. The two grade into each other, although, speaking generally, more hornblende occurs in the Greenwich and Wilton areas and parts of Monroe than in the mass north of Danbury.

* See note on page 86.

The rock is prevailingly porphyritic, with pink or white phenocrysts of feldspar, closely crowded, often attaining a length of one to two inches. The ground-mass in which the larger feldspar crystals are set consists essentially of two varieties of feldspar, quartz, and biotite or hornblende or both.

Metamorphism has produced gneissoid structures within the Danbury granodiorite. Usually the planes of foliation are some distance apart, thus giving the rock a massive appearance, and allowing large blocks to be quarried. In the vicinity of Greenwich the hornblendic variety is very fissile, and splits readily into even slabs suitable for curbing. The phenocrysts have been crushed in places and drawn out in lenses or eyes, thus producing an "augen" structure similar to that seen in the Glastonbury granite-gneiss. Where the rock has been more severely metamorphosed it passes into a hornblende-mica gneiss or even into a schist.

Granitic and pegmatitic injection has played a part in giving the final appearance to the rock, and makes it difficult to draw satisfactory boundary lines between this formation and the granites.

The Danbury granodiorite-gneiss is igneous in origin, and was intruded prior to the time when metamorphic action converted igneous and sedimentary rocks alike into gneiss and schist.

Thomaston Granite-gneiss [14].— This name is given to a number of masses of gneissoid granite, some of which are of considerable size. The larger tracts occur in Thomaston, Goshen, Weston, Westport, New Canaan, and Waterbury, while smaller masses and dikes cutting other formations are widely distributed. Foliation has been quite unevenly developed in the Thomaston granite-gneiss, and the rock accordingly varies in structure from almost massive granite to distinctly schistose phases. "Where least metamorphosed, as at the Plymouth quarry at Thomaston, and at localities on Candlewood Mountain, the rock is remarkably white in color, has a medium grain, and is flecked by numerous small scales of mica (biotite). The white base of the

rock is made up of about equal parts of a white feldspar (microcline) and quartz. Locally, as in the Wilton area, it is distinctly porphyritic, with phenocrysts of microcline, which sometimes reach one-half an inch in length. Examined in thin sections, with the aid of the microscope, the rock is found to be almost wholly composed of microcline, quartz, and biotite, with minute quantities of zircon and apatite. The gneissose varieties, such as the 'granite' quarried at Mine Hill in Roxbury, have marked secondary foliation. and a silvery mica has been extensively developed in membranes which cover the planes of foliation. This mica is often present in excess of the biotite. The latter mineral appears, however, in these varieties of the rock, in the same uniformly distributed equidimensional flecks which are characteristic of the massive varieties. The microcline of the gneissose varieties is further shown by the examination to be crushed and even granulated." *

That the Thomaston granite-gneiss is of igneous origin is shown by the fact that it so often occurs as dikes, and that fragments of other rocks are included within it. Similar evidence is afforded by the development of the epidote as a contact mineral. It is largely due to the injection of this granite-gneiss that certain gneisses like the Becket have developed locally such a decided banded structure. For the same reason it is very difficult in certain areas to distinguish the Becket and other gneisses from the Berkshire and Hartland schists.

Pegmatite.—As explained on page 71, pegmatite is essentially a giant granite, the individual crystals of which may reach the dimensions of a foot or more. Rock of this type occurs commonly throughout the western crystallines, in dikes or veins of small width compared with their length. Whether these are to be considered as dikes or veins depends upon the idea of their method of origin. Some of them are doubtless true veins in which the material has been deposited from heated waters; others are pretty clearly offshoots from granitic masses; and, as might be expected,

* W. H. Hobbs.

there is every gradation between the two types. Pegmatite is most abundant near granite areas, and is particularly prominent in the knotted variety of the Berkshire schist. In addition to the dikes and veins, two larger areas of pegmatite, situated respectively in the vicinity of Plymouth and Bethlehem, are doubtless parts of still larger deep-seated masses. Where pegmatite is abundant, the topography shows numerous white knobs. In composition the rock consists of feldspar (microcline, orthoclase, and albite), quartz, muscovite, biotite, and a number of accessory minerals, for example beryl, tourmaline, garnet, magnetite. In the larger pegmatite areas feldspar and quartz often occur intergrown to form graphic granite, and the constituent minerals attain a length of several inches. Pegmatite is apparently the last intrusion in the western crystalline rocks, as shown by the fact that dikes of this material intersect the granite-gneisses, which in turn cut the other formations of the region.

Litchfield Norite.— Certain dark gray rocks forming parts of Mt. Prospect, near Litchfield, have been called by Professor Hobbs Litchfield norite. This rock does not form large masses, but is found associated with granodiorite, diorite, and amphibolite. The area is not shown on the geologic map. Norite consists typically of plagioclase and orthorhombic pyroxene, usually hypersthene. In the Litchfield rock the feldspar is prevailingly labradorite; and, in addition to hypersthene, green hornblende and biotite are the most prominent constituents. Chalcopyrite and nickeliferous pyrrhotite are found in the less feldspathic parts of the norite. The presence of these minerals is responsible for the numerous unsuccessful attempts to secure nickel in commercial quantities at Mt. Prospect. As regards texture, the rocks are usually granitic, rarely porphyritic, and vary from fairly fine-grained rocks to those composed of crystals averaging one-fourth of an inch in diameter. Analyses of types of this rock, made in the laboratory of the United States Geological Survey, and published in Bulletin 228, show a wide variation in composition. "All the types of norite.

hornblende norite, mica-hornblende norite, mica diorite, hornblende-mica diorite, hornblende diorite, hornblendite, hornblende saxonite, hypersthenite, and lherzolite are found." *

The norite is of igneous origin, and its many varieties are largely due to differentiation during the process of cooling.

Amphibolite [38].— Distributed irregularly over the area occupied by the ancient crystalline rocks are dikes, lenses, and irregular masses of amphibolite. In nearly all cases this rock has a distinctly gneissoid structure, and is composed in large part of porphyritic feldspar and green hornblende. There is also a subordinate amount of quartz. The more massive types of amphibolite present a dark green base, mottled by areas of white feldspar occasionally reaching a diameter of an eighth of an inch. In favorable localities these feldspars are drawn out into lines. Where the rock is distinctly a hornblende gneiss, it is made up of alternating bands of feldspar and green hornblende. Locally, as in East Litchfield and Canton, garnet is developed, and near Bakersville and Collinsville the rock contains considerable greenish yellow epidote. Portions of the amphibolite are metamorphosed lenses of impure limestone, but in most cases the probability of its igneous origin is strong. It occurs distinctly as dikes, and its composition and texture are exactly those of a metamorphosed hornblende diorite. The amphibolite is older than the intrusive granites in the crystallines, as shown by the fact that dikes of the latter cut the former. Further, the fact that the amphibolite is interfolded with the Becket gneiss, Hartland (Hoosac) schist, etc., shows that its intrusion must have preceded the deformation which produced the major part of the metamorphism in this region.

Hornblendite, Soapstone, etc.— In addition to the amphibolite, there are small areas of basic rocks in western Connecticut which are related in a general way to the peridotites and pyroxenites. Among these are the areas of

* W. H. Hobbs.

hornblendite one mile north of West Cornwall station, two and one-half miles south of Still River, and at South Norfolk; and areas of soapstone and associated rocks three miles west of Torrington, a mile and one-half south of Bakersville, one mile north of Pleasant Valley, two and one-half miles south of New Hartford. Bowlders of soapstone, called locally "cotton rock", are found between Bristol and Hartland. When fresh, these soapstones consist of actinolite or tremolite with more or less greenish brown hornblende and biotite. The soapstone contains anthophyllite or tremolite, talc, and serpentine. The latter mineral occurs both massive and fibrous (chrysotile, often called asbestus).

Diabase Dikes [39].— Certain dikes of dark colored igneous rocks occur in the crystallines of western Connecticut, which are unlike the amphibolites. They are dikes of diabase forming two more or less interrupted narrow bands, one extending from Fairfield to the north line of Derby, and the other through the towns of Orange and Woodbridge. In most places the dikes constitute ridges or small elevations in the surrounding metamorphic rocks, but occasionally they have no distinct topographic development and are recognized only by their composition and texture.

In surface appearance the rock is quite uniform, a dark blue, firm stone, differing in no essential particular from the trap of the Connecticut Valley region. The material composing the dikes consists principally of labradorite and pyroxene; it is broken by faults and joints, but does not show traces of regional metamorphism. On the other hand, the schists and gneisses into which the diabase is intruded are somewhat altered and baked. The unchanged diabase masses are believed to be of Triassic age, and thus are much younger than any other formation represented in the Western Highland of Connecticut. Like the trap rocks found elsewhere, these dikes furnish excellent material for road metal.

GEOLOGICAL FORMATIONS OF THE EASTERN HIGHLAND.

All of the state of Connecticut east of a line extending from Lighthouse Point, New Haven, to Somers, is made up of ancient crystalline rocks, nearly all of which have been affected by intense regional metamorphism. The formations in this section of the state have not been so carefully studied as those west of the Triassic area, and many of the statements regarding them are to be considered preliminary and subject to radical revision. In some cases the boundaries of the formations have been of necessity arbitrarily drawn, because the rocks seem to grade into one another, and yet to present such differences as to make it worth while to give them separate names.

The geological formations occurring in the Eastern Highland may be summarized as follows:— The Monson and Branford granite-gneisses, and the Mamacoke gneiss are probably igneous in origin and of very great age, and may represent pre-Cambrian masses. The Glastonbury granite-gneiss is of uncertain origin. The Bolton, Brimfield, and Woodstock schists, Pomfret phyllite, Plainfield and Scotland schists, and Putnam gneiss are doubtless the metamorphic equivalents of sedimentary strata of varying composition. The relation of these sediments to the igneous gneisses has not been made out, and there is practically no evidence in the field which determines the position of these formations in the time scale. The discovery of fossils of the Carboniferous period in the Worcester phyllite, which is probably the equivalent of the Pomfret phyllite, suggests a late Paleozoic age for most of the schists east of the Connecticut River. This view is strengthened by the evidence presented by the geological formations of central Massachusetts, where they have been studied by Professors Emerson and Perry. However, there is great similarity between the Bolton schist and the Hartland (Hoosac) schist; between the Woodstock and Plainfield quartz schists and the Poughquag quartzite; and between the Brimfield and the Berkshire schist. It is not at all impossible that more extended investigations may reveal evidence that the meta-

morphic rocks of the Western Highland are related to those of the Eastern Highland in time as well as in lithologic character. No organic remains have been found in the crystalline rocks of eastern Connecticut, and so long as fossil evidence is lacking no definite statements can be made regarding the stratigraphic position of the different formations. The Eastford, Sterling, Canterbury, Maromas, Haddam, Stony Creek, Lyme, and New London granite-gneisses, and the Preston gabbro-diorite, are intrusions in earlier strata; but were intruded before the time of the metamorphism that reconstructed the rocks of the entire state, and are accordingly much modified by the development of gneissoid and schistose features. The Hebron gneiss and the Middletown gneiss are of uncertain origin; the Willimantic gneiss is merely a more injected phase of the Hebron. Pegmatite and amphibolite are found cutting all of the formations mentioned above, and occasionally small lenses of limestone are found. The Westerly granite with its various types in the southeastern part of the state is later than the pegmatite, and is therefore the latest of all the formations, with the exception of dikes of diabase, probably of Triassic age, which extend in broken lines from the Sound to the Massachusetts border.

Glastonbury Granite-gneiss * [15].— The Glastonbury granite-gneiss occupies an area extending from the north line of the state in Somers and Stafford to Portland, with a width varying from one and one-half miles at Vernon to about four and one-half miles in Glastonbury. It is bordered on the east by the Bolton schist; and throughout the greater part of its extent forms the eastern border of the Triassic sandstone, from which it is everywhere separated by faults. The Glastonbury granite-gneiss extends into

* For data regarding the formations in the vicinity of Middletown the Connecticut Survey is indebted to Professor L. G. Westgate, who made geological investigations in this region at various times from 1896 to 1899. In 1900 Professor Westgate served with Professor Gregory on the U. S. Geological Survey, and presented an unpublished report, parts of which are incorporated in the present work in the descriptions of the following formations: — Glastonbury granite-gneiss, Bolton schist, Monson granite-gneiss, Middletown gneiss, Maromas granite-gneiss.

Massachusetts, and is the equivalent of the Wilbraham gneiss of Emerson.

Topographically this formation constitutes highlands throughout its extent, forming the ridges which are so prominent east of Hazardville, Rockville, Manchester, and Glastonbury. At Sandstone Mountain in Somers the rock attains an elevation of six hundred feet, and is scarcely less elevated through a large part of Glastonbury. Roughly speaking, the area may be divided into two parts — a broad western portion, decidedly gneissoid and usually dark colored, with a large quantity of biotite and hornblende; a narrower eastern portion, more granitic, and in places reaching the massiveness of a true granite.

"The more granitic facies of the Glastonbury gneiss is shown in exposures on the hill north of Great Hill Pond. Outcrops are abundant along the road at the top of the hill, and a small quarry has been opened in the woods east. The rock in the quarry is a quite massive, medium-grained biotite-granite, with scattered areas of quartz and feldspar, the latter sometimes approaching crystal form, while the main part of the rock is an aggregate of smaller quartz and feldspar grains." *

The larger part of the Glastonbury gneiss, however, is very different in its typical development from the rock which has just been described. As seen in the abundant exposures west of the Portland reservoir, it is a dark, well foliated, almost schistose gneiss, of fine grain, which on the cleavage surface shows alternating patches of black biotite and white feldspar. An examination with the lens shows minute yellow-green grains of epidote scattered among the feldspar aggregates, or more abundantly associated with the biotite. The epidote does not seem to be derived from the decomposition of any elements of the rock, for all are remarkably fresh. The presence of biotite and hornblende, arranged in parallelism with aggregates of feldspar, gives a distinct foliation and banding to the rock. Quartz is abundant, and orthoclase, microcline, plagioclase, titanite, and

* L. G. Westgate.

apatite occur. When numerous outcrops in this region are examined, it is evident that there is no sudden break between the gneissoid and massive varieties of this formation, but that they grade into each other.

This gneissoid type of rock prevails throughout the larger part of the area. The strong foliation, the abundance of biotite and hornblende, and the almost universal presence of epidote in small grains, distinguish this rock from the more granitic type to the east. Towards the west side of the Glastonbury area the rock is apt to be darker and more foliated, because of the larger amount of biotite and hornblende present. This more schistose variety forms the hills southeast of Glastonbury, and occurs in the bed of Roaring Brook in South Glastonbury. At this latter locality the rock is a very schistose granulitic gneiss, with lenticular masses of feldspar parallel to the foliation (the so-called "augen"), and containing flattened lenses or patches (technically called "schlieren") of darker material up to a foot or more in length. The rock has very much the appearance of having been crushed, but it is rare to find under the microscope clear evidence that crushing has taken place. "It is not uncommon, especially in the northern part of the area, to find outcrops of augen-gneiss associated with this western facies of the Glastonbury gneiss. As has already been indicated, the schistose variety in Roaring Brook is an augen-gneiss. These augen, pink or white in color, are generally granulitic aggregates of feldspar; but sometimes, especially further up the brook, they are sub-porphyritic feldspars. The augen aggregates are often drawn out at their ends into narrow lines, which run in among the micaceous portions of the rock." *

The more massive variety of this gneiss is seen in the small quarries north of East Glastonbury. The rock here is a light colored, fine-grained biotite gneiss or granite, which sometimes is quarried in blocks two or three feet in thickness, with no sign of a parting. Some bands are

* L. G. Westgate.

denser, with reddish feldspars, and approach an augen-gneiss. Schlieren occur, oval or lenticular, or sometimes drawn out parallel to the foliation. A section of one of the schlieren shows a much larger proportion of biotite than appears in the main part of the rock, and abundant epidote, in which respects it resembles the more foliated varieties of this formation. Another quarry occurs in this more massive gneiss three-quarters of a mile north of the village. The rock is a light gray, porphyritic, granitic gneiss. It is rather thick-bedded, and would make good curbing. The porphyritic feldspars sometimes reach a length of an inch, are single crystals or Carlsbad twins, and lie roughly parallel with the bedding. The rock is a foliated gneiss and contains epidote. Under the microscope the feldspars of the porphyritic areas do not show the same freshness as the rest of the rock. Epidote often holds its form against the biotite, and does not seem to be of secondary origin. It is commonly found grouped towards the center of the plagioclase grains, is rare in the microcline, and is not found in the quartz.

Thus in general the Glastonbury gneiss has "a double character — a granitic biotite gneiss or a biotite granite in a narrow band along its eastern margin; a darker, well-foliated gneiss with biotite, hornblende, and epidote in the remainder of the area. But this foliated gneiss becomes sometimes near the margin almost a schist; and, again, at localities well within the margin, quite massive; and both massive and schistose phases sometimes become augen-gneiss." *

Near the boundary between the Triassic strata and the Glastonbury granite-gneiss, the rock often appears as a rusty micaceous gneiss that has evidently undergone crushing. In places it becomes highly schistose, and contains sericite and biotite largely altered to chlorite, with a number of accessory minerals. It is believed by Professor Westgate that this facies of the Glastonbury gneiss is due to the movements connected with the faulting and deformation of the belt along the Triassic border.

* L. G. Westgate.

"In regard to the origin of the Glastonbury gneiss, there is strong indication that it is in large part igneous; and this applies both to the more massive eastern portion, and the more gneissic variety on the west. The former, in its outcrops in the quarry north of Great Hill, and in numerous bowlders scattered over the area to the south, reaches a massive character typical of a granite. The general and sometimes very marked foliation of the western part of the area certainly does not at first suggest an igneous rock; yet all intermediate steps can be found between this and the massive granite to the east. Within the area of well foliated gneiss, bands of more massive augen-gneiss are found, very similar to the augen-gneiss of the Maromas area, which is in all probability of igneous origin. Again, the presence of dark patches or schlieren is a strong evidence of its igneous origin. These are found, as has already been pointed out, in the most schistose facies of the gneiss, as seen in the bed of Roaring Brook in South Glastonbury, and they are found in the more massive facies, as illustrated at the East Glastonbury quarries [and at other localities]. Whether such dark inclusions are metamorphosed and melted masses of schist, or are basic segregations formed in the rock previous to solidification, is immaterial as to their bearing on the origin of the rock. In either case they are inexplicable on the supposition of its sedimentary origin." *

The igneous origin of the Glastonbury granite-gneiss is further indicated by the contact phenomena exhibited along its borders. At the top of Collins Hill in Portland the contact between the gneiss and the Bolton schist "is sharply defined, and the gneiss and schist are perfectly distinct. The line of the contact is irregular, and inclusions of schist [similar to the Bolton] occur at several points in the gneiss. This same biotite gneiss occurs for a short distance down the hill to the east, and can be followed north along the line of contact for a quarter-mile." * The contact phenomena shown at this locality suggest an eruptive

* L. G. Westgate.

origin, but the evidence from the field as a whole is inconclusive.

Bolton Schist [16].— The Bolton schist occurs as a belt rarely exceeding a mile in width, and extending from the northern line of the State at Stafford to Great Hill, which forms the boundary between Portland and Chatham. At Cobalt the belt divides, and sends one arm to the northwest, wrapping about the Glastonbury gneiss, and another arm to the southeast, extending a little beyond the Connecticut River. A partially detached area of Bolton schist extends along the eastern border of the Triassic from Portland to Lake Quonnipaug in Guilford.

Throughout its entire extent the Bolton schist is a marked topographic feature, and constitutes a high ridge or series of ridges. The belt from Great Hill to West Stafford is almost a continuous ridge, rarely under five hundred feet in elevation, and cut through by streams at West Stafford, Bolton Notch, and Dark Hollow. The southern belt has its culminating points in the White Rocks and Chestnut Mountain.

The Bolton schist is a silvery sericite schist showing considerable variation in character, and includes gneissoid bands as well as beds of quartzite and marble. Besides feldspar, quartz, muscovite, and sericite, the rock contains biotite, garnet, and staurolite in abundance. In places the schist contains the latter minerals in such quantity that it might be properly classed as garnet schist or staurolite schist. Magnetite, graphite, fibrolite, pyroxene, rutile, pyrite, and chlorite also occur. Any one or more of these minerals may be absent from a given outcrop.

One of the best exposures of this rock is along a road through the ravine which cuts across the schist range, about a mile north of the northeast corner of Middlesex County. On the west the rock is a silvery sericite schist, everywhere containing abundant garnets, and generally small prisms of staurolite. Farther to the east, and beyond the ravine, the Bolton schist is represented along the road by a dark fine-grained biotite gneiss, the minute brown biotite flakes of

which give a distinct purplish color to the sandy or gneissic facies of the Bolton, and indicate its gradation into the Hebron gneiss. Two miles southwest the silvery schist again appears. Garnets and staurolite prisms are abundant, and the microscope reveals much magnetite dust, and abundant films of sericite, curving around and between the quartz, garnet, and staurolite, and also shows an equal amount of brown biotite in smaller, usually unbent flakes. This same rock is exposed in numerous outcrops along the east side of the range, west of Lake Pocotopaug. It is here that staurolite occurs in its largest development, the prisms reaching two or three inches in length, and a half-inch in their longest diagonal. The Bolton schist along its eastern border near the north end of Lake Pocotopaug, and in a corresponding position farther north, is prevailingly a fine-grained biotite gneiss, passing into a biotite schist. Staurolite schist again occurs along the south face of Great Hill, but it here lacks the silvery sericitic character it has farther north, and becomes a sandier and more gneissic biotite schist, with garnet and staurolite. The schist along the west side of the Bolton belt is not always staurolitic; garnets are almost invariably present, but staurolite, while abundantly present in certain exposures, is absent in many others.

Good exposures of the Bolton schist occur also along the Air Line railroad for more than a mile east of Cobalt station. Immediately at the station the rock is a medium-grained biotite schist, the mica laminæ often closely crumpled, and alternating with thin layers of quartz. Weathered outcrops show the rusty appearance characteristic of the schist. The rock exposed in the railroad cut a mile and a quarter east of the station, is a fine-grained schist, containing beds of gneiss. Its color is gray when freshly exposed but becomes rusty on weathered surfaces. The abundant biotite is often bleached, and forms wavy laminæ about knots of quartz. Small grains of pyrite are found in association with the other minerals. The rock is grayer and less silvery than the staurolite schist found farther north. The gneissic bands are also fine-grained, and

the small scattered biotite flakes are hardly numerous enough to produce a distinct foliation in a hand specimen. Small garnets are present. The gneiss occurs in beds of greater or less thickness, interbedded with the schist, and all are evidently parts of the same formation. In some cases the gneissic bands more or less completely lose their biotite, and a quartzose type of rock is produced identical with phases of the Hebron gneiss, and closely resembling a quartzite.*

It is interesting to note that this section, showing silvery schist with garnet and often staurolite, followed by alternating beds of schist and quartzose gneiss, is reproduced in the section at Bolton Notch, and at points still farther north towards the state line. The sandy quartzose layers, however, attain, in the more northern localities, a development and a character of their own, which are lacking in the corresponding rock of the south.

The rock exposed at Diamond Lake in Glastonbury, in Bolton, in Tolland, and farther north, is much more prevailingly sericitic, and oftentimes takes on a graphitic appearance, becoming dark and lead-colored. At a number of points near the northwest border of the formation the schist is much shattered and seamed with quartz, dark gray in color, and finely granular in texture, instead of presenting distinct foliation surfaces covered with films of mica. In these places the rock is closely folded and otherwise distorted. This peculiar facies of the schist has been ascribed to mechanical movements associated with the faults along the border of the crystalline area.†

At a number of localities in the Bolton schist, as shown in the cut on the Air Line Division northwest of Job's Pond, there occur bands and lenses of impure limestone. These bands are interbedded with the schist, and have taken part in the faulting to which the schist in general has been subjected. Wherever the limestone occurs it is fine-grained, grayish in color, and contains light greenish patches of

* The above paragraph and the one preceding are taken substantially, though not *verbatim*, from the unpublished report of L. G. Westgate.

† L. G. Westgate.

pyroxene. Usually more or less mica occurs with the limestone, and at Bolton Mountain and elsewhere it grades into a calcareous mica slate.

Quartzite in the Bolton Schist.— Bands of quartzite and quartz schist occur in the Bolton formation; but, although these bands are of considerable extent and characteristic, it does not seem practicable to treat them as a distinct formation. The quartzite shows a wide range, from almost pure quartz like that of veins to quartzose mica schist. In the southern part of the area it forms the summit of Great Hill, and has been traced northward along the range for three miles. Towards the north it becomes thinner, is a less marked topographic feature, and has not been identified in place beyond a point southeast of Meshomasic Mountain. East of the quartzite, which occupies the summit of the range, occurs the typical Bolton schist. To the west, wherever exposures are found (and they are rare, and never within a half-mile of the quartzite), the rock is a granite-gneiss. "Quartzite and schist alike dip to the west, so that, unless we are here dealing with an overturned fold, the quartzite is the uppermost member of the Bolton schist which is exposed in the range. The rock is sometimes a massive quartzite, with small quantities of muscovite in minute scattered grains. Then, with an increase of muscovite, the rock becomes foliated and in extreme cases schistose. Constant alternations occur in the ledges, between the more massive and more schistose varieties. At a few points the rock takes on an appearance which suggests a conglomerate."* Toward the north line of the state the quartzite is much more schistose in structure, and is nearly always micaceous. Besides the minerals mentioned above, pyroxene, magnetite, rutile, and rarely chlorite, occur in the rock.

At a point west of Pocotopaug Lake the rock has been quarried on a small scale for whetstones. Other quarries were formerly worked in Bolton and West Stafford. The abandoned quarry at Bolton Mountain was at one time

* L. G. Westgate.

famous for its flagstones, which may be now seen on the streets of the larger Connecticut cities.

Lenses and dikes of amphibolite are so abundant in the eastern part of the Bolton schist that they were considered by Percival as a separate formation. Usually the amphibolite is schistose, but in places it is gneissoid, and generally contains pyroxene, epidote, and chlorite.

Pegmatite occurs, usually in narrow veins distributed haphazard throughout the schist; but at the White Rocks, east of Middletown, it forms a large part of the outcrop, and varies from a white granular rock to a giant granite with crystals of feldspar several inches in length.

The general dip of the Bolton schist is towards the west, and throughout its extent it is much folded or crumpled. It is believed to be of sedimentary origin, and to be the metamorphosed equivalent of a stratified series consisting of sandstones, shales, and some limestone. Its sedimentary character is indicated by its great variation in field appearance and in mineralogical and chemical composition, as well as by the presence of marble, quartzite, and graphite. In many respects this formation resembles the Hartland (Hoosac) schist. The Bolton schist doubtless had originally much greater extent than at present, and was the country rock into which the Maromas, and probably the Glastonbury, gneiss was intruded. No fossils have been found in it nor in any adjoining rocks (except the Triassic sandstones), and it is therefore impossible to assign the formation to a definite place in the time scale.

Monson Granite-gneiss [17].— Bordering the Bolton schist on the east is a band of gneiss extending in a southwesterly direction from the northern boundary nearly across the state. Northward it extends into Massachusetts, and the rock is extensively quarried in the town of Monson, from which locality the entire formation derives its name. The rock is exposed in ledges in many localities, and forms a large part of the bowlders which are strewn so abundantly in the valley of the Willimantic River, from the Massachusetts line southward. The best exposures of this rock

within the state are found in quarries along the Connecticut River. At Arnold's Station in the town of Haddam, quarries have long been worked on a high hill near the station, and the stone taken out has left a deep trench extending directly through the summit of the hill. The quarried rock has been used for curbs and block pavement. Where typically exposed, the rock is a fine-grained, dark gray, uniform biotite-hornblende gneiss, marked at short intervals by parallel seams of quartz with some biotite and hornblende, along which the rock is generally split in quarrying. This rock is somewhat darker than the darker variety quarried in Monson. Across the river at Haddam Neck several quarries have been opened on the hills facing the river. These quarries are not at present being worked. The rock here is gray, fine-grained gneiss, lighter in color than that at Arnold's. As seen in the quarries, it consists of alternate light and dark bands, which are nearly vertical, and parallel to which the foliation has been developed. Biotite is the most abundant dark constituent, and generally the only one, though in some cases hornblende is the more abundant mineral. Orthoclase and plagioclase, quartz, and garnet are present.

Where the rock is quarried, both north and south of the river, it is a uniform and generally rather light colored gneiss, and is not marked to any extent by the presence of intercalated bands of dark hornblendic gneiss or amphibolite. This would naturally be the case with those portions of the rock chosen for quarrying. Such bands of amphibolite are, however, quite characteristic of the gneiss belt as a whole, and there is scarcely an outcrop of any extent which does not show one or more of them. In many instances these amphibolites form narrow and distinctly foliated bands, parallel to the structure of the enclosing gneiss, but sometimes they cut across the foliation obliquely, and they are often of a massive character, which strongly indicates an eruptive origin; so that it is considered probable that most if not all of the amphibolite, which forms such a striking contrast to the light colored gneiss, is igneous.

The Monson gneiss is believed to be igneous in origin. Its uniformity of texture and composition over wide areas, and the absence of minerals distinctly characteristic of sedimentary rocks, testify to an original igneous mass. It is suggested that the bands of amphibolite and granite-gneiss, which make up this formation, have been developed by metamorphism from original masses formed by segregation when the rock was yet in a molten condition. This formation was formerly considered as of sedimentary origin, and has been described as a metamorphosed conglomerate.*

Brimfield Schist [18].— One of the largest sections of metamorphic rock in the eastern division of the ancient crystalline rocks is that occupied by the Brimfield schist, covering practically all the towns of Union, Ashford, and Willington, and large parts of Woodstock and Stafford. The formation extends northward into Massachusetts, and has received its name from the town of Brimfield in that state. Toward the southwest it extends to Bolton.

Throughout its whole extent this formation shows striking uniformity in the general character of the rocks. It contains numerous varieties, but all of them are peculiar to this area. Perhaps the most conspicuous feature of the Brimfield schist is its rusty color, caused by an abundance of disseminated grains of iron. The soil formed from it is generally reddish or yellowish in color. The typical Brimfield schist is a rusty, dark colored or purplish rock, showing great variation in the development of schistosity. The mica in the rock is in places white and silvery muscovite, but more commonly biotite, with a reddish or purplish tint. It may occur in flat crystals, or it may be drawn out into fibres. Garnets are generally abundant in the schist as well as in the subordinate bands of gneiss which occur with it. In addition to the mica and the usual feldspar and quartz, there occur also sillimanite and graphite. The sillimanite occurs in clumps, clusters, or sheaves, or in individual needles scattered throughout the rock, and forms one of the charac-

* Emerson, *Geology of Old Hampshire County, Massachusetts*, United States Geological Survey, Monograph XXIX.

teristic features of this formation. Graphite occurs in small fragments with metallic luster, and occasionally in sufficient abundance to attract a prospector. Abandoned "lead" mines are found in parts of Ashford, Union, and Mansfield, as well as farther north, in Massachusetts. The iron in the rock is so abundant that it has been mined in certain localities. Near Staffordville ore was taken out in some quantity between 1840 and 1850. Here the ore was of two varieties — the common bog iron ore, limonite; and a reddish or yellowish earth which came from the decomposition of rocks in place.

In certain belts extending in a north-south direction the Brimfield schist takes on a gneissoid character, doubtless due to enrichment by quartz and feldspar along the planes of foliation. So marked is this arrangement of the gneiss and schist that the formation may be considered as a series of alternating bands of schist and gneiss.

Beds of hornblende and of pyroxene occur in this formation; also thin beds of impure limestone; and in places pyrite becomes a prominent constituent, and has given the name of "sulphur rock" to certain ledges.

Brimfield schist is not markedly folded or crumpled, having in general a quite uniform schistose or slaty character. About the areas of intruded granite, however, the rock is often much crumpled. In such localities the schist is occasionally marked with knobs and little knots, which closely resemble similar structures in the Berkshire schist.

It is believed that the Brimfield schist is the metamorphosed equivalent of sediments prevailingly argillaceous, but including also sandy and calcareous beds. The part of the Brimfield included in Massachusetts is believed by Emerson and Perry to be of Carboniferous age, but as yet no evidence on this point has been found in Connecticut.

Eastford Granite-gneiss [19].— Extending through the towns of Woodstock and Eastford to Chaplin is an area of gneiss averaging a little over two miles in width. The rock in general is a light or dark gray gneiss, fine-grained, or in places even porphyritic. Lines of schistosity are well

developed, and only a very slight amount of folding or crumpling has taken place, so that the rock is suitable for quarrying. At the "ledges" near Eastford village the rock is a biotite-muscovite gneiss, light colored, and containing much quartz and feldspar arranged along definite lines. Perhaps the best exposures of this formation are in the southeast corner of Eastford, where considerable quarrying has been carried on in past years. Here the rock is distinctly gneissoid in parts, and in other parts it is massive, with a uniform texture and regular structure throughout. The differentiation into light and dark gray varieties is not a prominent characteristic in this section, but small flattened lenses of biotite give the rock much the same appearance as that possessed by the Monson gneiss. Like most of the gneisses in the state, this formation is cut by seams of granite and pegmatite, with an occasional bed of amphibolite. Both the granite and the amphibolite dikes are later in age than the country rock. The composition and texture of the Eastford granite-gneiss, as well as its field occurrence, suggest an igneous origin.

Woodstock Quartz Schist [20].— There are two areas of quartzose rock in the northeastern part of the state, named respectively the Woodstock and the Plainfield quartz schist. The Woodstock quartz schist extends through the eastern part of Woodstock, and continues southward through Pomfret, terminating near the western border of Hampton. This area is deeply covered by glacial deposits, and few outcrops have been located. In character the schist varies from an almost pure quartzite to a mica schist with abundant quartz grains. Near North Woodstock the schist is a purplish rock consisting of quartz, sericite, and muscovite, and varies in texture from a rock which is practically sandstone to a very micaceous or, rarely, a chloritic schist. In places hornblende in small green crystals is distributed generally through the rock, giving a greenish tint to certain layers. The Woodstock quartz schist is believed to represent sedimentary sandstones and clay rocks. The original quartz grains are now partly converted into crystals of

quartz, and the argillaceous material is now represented by the micas. Rarely calcareous bands occur. "Quinnebaug whetstones" were formerly quarried from the fine-grained quartzite. The continuation of the Woodstock quartz schist in Massachusetts has been separated into several distinct formations.

Pomfret Phyllite [21].— Skirting the eastern border of the Woodstock quartz schist, and extending south into Hampton, is a narrow belt of mica slate or phyllite. A detached area occurs in Bozrah and Franklin, and it is possible that the two are connected by a narrow band extending along the valley of Little River. Where typically developed, as in the northeastern part of Pomfret, the phyllite is well foliated, the foliation planes being made of minute flakes of mica, which give the rock a purplish tone and a silky luster. The rock of this type continued northward seems to be the equivalent of the "Worcester phyllite" of Perry and Emerson. In addition to the typical phyllite, this formation also exhibits distinctly schistose varieties, containing much muscovite in fairly large plates. This type is traversed in places by calcareous seams, with which hornblende crystals are associated. In places long fibrous minerals are arranged in sheaves and bunches along foliation surfaces in such a manner as to simulate fossils.

Putnam Gneiss [22].— Extending from the northeastern corner of the state down along the valley of the Quinnebaug River, and reaching beyond Norwich, is an area of gneiss quite unlike any other formation in the state. This is the Putnam gneiss, and is extremely variable in texture and sometimes in composition. The rock is made up of bands of schist, gneiss, quartzite, and igneous intrusions in such variety that it is possible to collect several unlike specimens within a distance of ten to fifteen feet across the strike. In texture the rock varies from a compact bluish black slate and quartzite, through fine, black schist, to coarse, gray, quartzose schist and feldspathic gneiss. The formation also includes beds of limestone, sheets of Sterling granite-gneiss and peg-

matite, amphibolite, and layers of a black granite porphyry. In composition the formation shows gradations from a hornblende-biotite schist (or sedimentary amphibolite?) with little or no feldspar, through a quartz-biotite schist and gneiss (or crystalline arkose?), to a quartzite.

In the eastern part of the area, principally in the towns of Preston and North Stonington, where detailed work has been done by Dr. G. F. Loughlin, there are two main varieties — a gray schist, often feldspathic, and a fine biotite-hornblende schist, both thoroughly injected with intrusive sheets and stringers of granite and pegmatite. The fine black schist evidently underlies the gray feldspathic variety, and, where it comes into contact with the Preston gabbro-diorite formation, has the appearance of hornstone. The alteration to hornstone doubtless took place before the metamorphism occurred which recrystallized all the rocks of this region.

A characteristic feature of a large part of the Putnam gneiss is well displayed near Moosup village and in the railroad cut west of Putnam. Here the rock has the appearance of a conglomerate, more or less crushed and drawn out into lines. When the apparent pebbles are examined, they are seen to consist of feldspar crystals or small areas of quartz and feldspar, about which biotite and hornblende have been closely wrapped. It thus forms a metamorphic pseudo-conglomerate. The "pebbles" are seen not to be regularly distributed along the planes of schistosity. The crystals forming the "pebbles" of this rock owe their origin to granitic intrusion or to injection by hot solutions which have added to the original rock material for the formation of feldspar. It appears on fuller investigation that the layers of "conglomerate" are metamorphosed sheets of granite porphyry.

A typical outcrop of Putnam gneiss exhibits bands of black hornblendic schist alternating with gray gneiss, and shows numerous granitic injections. Surface exposures usually have a brownish or greenish color due to the alteration of the black minerals.

In addition to layers of slate and quartzite, the Putnam

gneiss contains at several points limited beds of dolomitic marble or limestone. The most important of these localities are near the northwest corner of North Stonington, and on the east slope of Swantown Hill, where lime-kilns were once operated on a small scale. There was also a kiln located on Follyworks Brook, a little over a mile northeast of Preston City. The limestone is completely crystalline, and is accompanied by various minerals, such as actinolite, tremolite, titanite, biotite, and feldspar, that have developed from the impurities in the dolomite as a result of metamorphism.

Although the Putnam gneiss presents such marked variation in texture and composition, and presents at all points such complicated structures, yet it has been derived from simple sedimentary rocks deposited in horizontal strata, and doubtless containing fossils. The slate, the quartzite, the limestone, and the occasional presence of graphite in the black schist suggest a sedimentary origin, and the formation is believed to have consisted originally of beds of sand and mud and deposits of impure limestone. At some date later than the original deposition and prior to the Triassic, the strata have been greatly modified by two processes — igneous injection and regional metamorphism.

The rocks constituting the Putnam gneiss were injected by granitic sheets and dikes and by hot aqueous solutions and vapors. The intrusions seem in large part to be parallel to the bedding. The intrusions include dikes and sheets of Sterling granite-gneiss, varying from masses one hundred feet in thickness to the finest stringers; pegmatite veins, also varying much in size, running down in places to mere veinlets of quartz; and sheets of black granite porphyry, with the larger phenocrysts exceeding two inches in length. Associated with the black porphyry are sheets of sheared diorite or hornblende schist varying in width from ten feet to a fraction of an inch. The coarser-grained of these sheets are easily identified as intrusive; but, in the case of some of the finer-grained ones, field evidence alone is not sufficient to determine whether the rock is igneous, or a metamor-

phosed sediment containing large amounts of iron oxides, magnesia, lime, and silica.

The severe metamorphism which is so evident in the Putnam gneiss represents several stages, some preceding, others following or accompanying the granitic intrusion. Near the larger intrusive masses the shales have been converted into hornstones, or into slates, schists, and gneisses; the sandstones have become quartzites and schists; and the limestones are now represented by impure marble. Schistosity has been developed in the entire area, and the gneiss is so closely folded and contorted that the same bed may occur several times in one outcrop. The extreme plication and the frequent recurrence of beds, together with the great and constant variation in texture, make definite correlation practically impossible.

The age of the Putnam gneiss is unknown, and the data at hand are insufficient even to determine its local stratigraphic position. The evidence indicates that the Putnam underlies the Scotland schist. The two formations are conformable, and pass into each other without noticeable change. All the igneous rocks of this district occur as intrusions in the Putnam gneiss, and this formation is therefore older than the various dikes, sheets, pegmatite veins, and igneous masses found associated with it. The isolated outcrops of gray biotite gneiss occurring in the Sterling granite-gneiss may be remnants of the Putnam gneiss; and, if so, the formation was originally of much greater extent, reaching southward perhaps as far as Long Island Sound, and eastward into Rhode Island.

Plainfield Quartz Schist * [23].—A band of quartz schist similar to that in Woodstock extends from the northeast corner of Thompson southward through Killingly, Plainfield, and Griswold, east of Pachaug Pond, and into North

* The geological formations in southern Windham and in northern New London county have been studied by Dr. G. F. Loughlin. During the summer of 1904 Dr. Loughlin was assistant on the Connecticut Survey, and later undertook a special investigation of the Preston gabbro-diorite and adjoining formations. Through the kindness of Dr. Loughlin free use has been made of his notes and manuscript in preparing the descriptions of the rocks of that region, especially of the Plainfield quartz schist, the Sterling granite-gneiss, the Lantern Hill quartz rock, and the Preston gabbro-diorite.

Stonington, while a shorter band lies parallel to it in Voluntown as far south as Pendleton Hill, and is separated from the larger area by an intrusive mass of porphyritic granite. Throughout its entire extent the rock is highly quartzose, but varies in its texture from a finely divided quartz schist to an almost massive quartzite, and again to a dark colored rock resembling slate. The slaty variety occurs in the vicinity of Pachaug Pond, and is less resistant to the weather than the lighter colored rock which is typically exposed in northern Plainfield and at Pendleton Hill. Farther to the south the quartz schist becomes finer in texture and more resistant; and where it appears at Ashwillet, or better yet at Barnes Hill, the rock is so dense and silicious that it might be called a quartzitic hornstone.

South of Barnes Hill and Prentice Mountain, the quartzitic hornstone fades out into scattered outcrops, and is not found south of the northern end of Swantown Hill; but it is possible that a continuation of this formation is found in a small outcrop of hornstone with well developed slaty cleavage, about half a mile north of Lantern Hill.

Outcrops of the eastern band of the quartz schist are not found south of Pendleton Hill; but the location of sharp, angular bowlders is such as to prove its continuance southwestward to the northern border of Wyassup Lake; while outcrops west of the lake show a gradation from the light quartzitic rock to the coarser, gray quartz-biotite schist of the lower part of the Putnam series, which becomes lost in the Sterling granite-gneiss. Another noteworthy band of the quartz-biotite schist can be followed for two miles or more along the road running east from North Stonington village.

In certain localities feldspar occurs as a constituent of the quartz schist, giving the appearance of a fine arkose or even of a granite. In fact, through parts of Plainfield the distinction in the field between the quartz schist containing feldspar, and the fine, aplitic contact phase of the Sterling granite-gneiss, is very difficult, and the position of the boundary of these formations is accordingly uncertain.

As regards stratigraphic position, the Plainfield quartz schist seems to be part of a series which includes the Putnam gneiss. North of Lantern Hill the slaty hornstone schist grades into the fine, black schist of the Putnam gneiss series, which suggests a conformable relation between the two rocks. This relation is also shown in the vicinity of Pendleton Hill, where the quartz schist underlies the biotite schist, and again is underlain by a similar rock, giving rise to the belief that the Plainfield quartz schist, instead of being an independent formation, is only a prominent and clearly marked variation of the Putnam formation. The Plainfield quartz schist seems to lie near the base of the Putnam series, and to be the oldest sedimentary formation in this region. Additional evidence of its age is afforded by the fact that it contains intrusions of the Sterling granite-gneiss, sheets of granodiorite, and stringers from the Preston bathylith.

Sterling Granite-gneiss* [24].—The eastern border of the state from East Killingly southward is occupied by an area of granite-gneiss, which has a further extension northward through Rhode Island and Massachusetts. It also extends in an elongated area, between the Putnam and Mamacoke formations, through the extreme northern parts of Ledyard and Montville. The Sterling formation is made up of two distinct types: a porphyritic gneiss, with an abundance of biotite along the foliation planes; and an aplite, or a granite-gneiss practically free from mica. The porphyritic type is always highly gneissoid, and the phenocrysts are drawn out into lenticular forms. These phenocrysts are of pink feldspar, and in some places attain a considerable length; elsewhere they are scarcely distinguishable from the groundmass. In the latter case, the rock shades into a normal granite, which, as far as mineral composition goes, is intermediate between the porphyritic and the aplitic types.

The aplitic type is probably a later intrusion than the porphyritic and normal types, since fine aplite dikes or stringers are sometimes found cutting the porphyritic rock.

* See note on page 132.

While these dikes are fine-grained, the aplite often forms large masses showing a medium and sometimes even a coarse grain. These masses are best shown in northern Ledyard, North Stonington, and northeastern Griswold. The rock consists principally of quartz and feldspar, with frequent grains of magnetite, sometimes in fairly distinct octahedral crystals scattered evenly through the mass. Both biotite and muscovite may be present or absent, but biotite is almost never prominent. When biotite is present, the rock is usually rather fine-grained, and appears to grade into the normal type. Muscovite in considerable amount is practically limited to the outcrops of highly gneissoid and sheared rock — a condition which strongly suggests, for part of it at least, a secondary origin due to dynamic metamorphism. Though a gneissoid structure is always more or less developed in the aplite, the variety destitute of mica has often a massive appearance, especially when seen across the planes of foliation.

In certain places where pressure and shearing were particularly strong, the rock of both types is highly contorted, and even converted into a muscovite schist by the effect of pressure on the feldspar. These sheared places are often accompanied by segregations of quartz, which, in some instances, has probably developed at the expense of the feldspar. Both types are injected by pegmatite of the same general composition as the aplite; and in several places the typical pegmatite can be traced into veins of gray, rather smoky quartz, which branch and continue as veinlets in the granite.

The general color of the granite-gneiss is pink to red, although, in some regions, where exposed in fresh cuts and quarries, it is light to medium gray. The color depends largely on the oxidation of the iron in the feldspar, and on the amount of the mica present. The pink color in the phenocrysts of the porphyritic type, and of the feldspar of the aplitic and pegmatitic types is evidently original, for fresh exposures show just as high a color as the weathered outcrops; and, in places, the weathered surfaces have even

become whitened by conversion of the feldspar into kaolin. But, where the phenocrysts are not prominent, the pink color is evidently due to superficial oxidation, and is found only in weathered specimens. The unaltered rock in such cases is gray in color, as is well shown in the large quarry at Oneco in Sterling.

With the exception of pegmatite injections, the Sterling granite is free from intrusions, except in the vicinity of Long Island Sound. In the region from Westerly to Groton there are large dikes of fine Westerly granite, which is, or has been, quarried at several places. At Westerly, both the fine Westerly, and the Sterling, or "red Westerly," granite are quarried; but the amount of the Sterling granite is much less than that of the famous fine-grained Westerly.

That the Sterling granite-gneiss is of igneous origin is beyond a doubt, as both the porphyritic and the aplitic type show the characteristics of granitic masses. Furthermore, basic segregations or *schlieren*, which are further evidence of igneous origin, are often found in the quarries, drawn out in the plane of foliation; and still further proofs are found in the frequent occurrence of isolated masses of the older Putnam gneiss included in the granite, and in the abundance of sheets of Sterling granite-gneiss intruded into the Putnam formation, and diminishing in size the farther they extend from the parent mass. In fact, the Sterling granite-gneiss is believed to be a bathylith underlying a large section of eastern and southeastern Connecticut, and coming to the surface in a number of localities mapped separately as granite outcrops and hills. Whether or not the Sterling granite-gneiss is related to the Canterbury granite-gneiss or to any of the granite-gneisses along Long Island Sound is not yet definitely known; but intrusive sheets occur as far west as Norwich, if not farther, and the aplitic type has been traced westward across the Thames River and on into Salem.

Lantern Hill Quartz Rock [24a].—At Lantern Hill, North Stonington, occurs an enormous mass of quartz, showing itself topographically as a conspicuous elevation.

The range is 1,000 to 1,500 feet in width, and fully a mile in length, extending from the southern end of Long Hill to the relatively low hill north of Lantern Hill, and descending into the narrow east-west valley beyond. The summit of Lantern Hill rises 520 feet above the sea, and over 400 feet above the surrounding country. The walls of the hill are nearly vertical, for a distance of 200 to 300 feet down from the top, while the base is surrounded by talus slopes of large quartz bowlders.

The true nature of the formation is not easily determined without a study of the surrounding country. The rock all around it is the aplitic Sterling granite-gneiss, which strikes nearly east and west, while the trend of the quartz range varies from N. 15° E. on Long Hill to due north on Lantern Hill. The whole range of hills is composed of milky quartz, with its surface usually roughened by frost action, and preserving evidence of close jointing in a direction varying from due north to N. 20° E. To all appearance Lantern Hill is an enormous simple quartz vein; but the hill north of the main mass, and also Long Hill, present evidences of a more complicated structure. In these places the quartz is distinctly foliated, often with sericitic or slightly chloritic mica along the planes of schistosity. The rock as a whole is porous and often mottled with rusty spots, and lacks cohesive strength, save for the numerous veins of pure white quartz, which traverse the porous material and form an intricate network. The larger white veins, usually extending in a north and south direction, are connected by numerous smaller veinlets, which diminish in size until they are hardly visible. The veins thicken in places, and branch until, when veinlets are sufficiently numerous, practically the whole rock is impregnated with the vein material, forming a mass of white quartz such as appears in the crest of Lantern Hill.

At the summit of Long Hill, where the surface of the ledge has been protected from frost action, the foliation of the porous quartz strikes in the same direction as that of the aplitic granite which surrounds the hill. This fact suggests the probability that the porous rock was originally

aplite, in which the feldspar has been destroyed and more or less completely replaced by other minerals. Where replacement was not complete, kaolin and ferric oxide were left, staining the rock in the places originally occupied by the feldspar. At the surface, the kaolin and iron rust have been removed by rain water, leaving the ridges of original quartz, perhaps reinforced by infiltrated silica, and held together by the series of branching veins whose general trend is transverse to the foliation.

Many of the veins are full of pockets ("vugs"), lined with small, finely developed quartz crystals; and a comb structure is also a common development. The structure of the whole formation is excellently shown at the Silex mine, situated near the southern end of Long Hill. Here the comb structure and pockets occur in distinct veins, which are often very close together, and connected by branches. Between the adjacent veins is powdery quartz, which can be mined with pick and shovel, without the aid of blasting. The wash of rain water often brings the comby veins into relief, showing the true character of the formation. The powdery quartz at the mine is quite free from iron stains, but frequently shows greenish micaceous particles. The veins forming the comb structure evidently follow a series of joints and minor fractures.

The contact between the quartz mass and the aplite is hidden by talus, but fragments occurring near the contact appear to be aplitic granite in which part of the feldspar has been replaced by quartz. More satisfactory evidence as to the nature of these quartz masses is furnished by outcrops on Swantown Hill and also near Glasgo village. On the northern end of Swantown Hill and also on the hill lying west of it occurs a network of veins, occasionally with comb structure developed. The rock between the veins closely resembles the fine-grained Sterling aplite. Another ledge, north of the village of Glasgo and a little south of the Whipple homestead, shows ramifying quartz veins in schistose aplite, the larger veins following the foliation planes. Here all stages may be traced from pure quartz to unaltered

aplite, with intervening stages of porous quartz and highly silicified aplite. The weathered surface where replacement is incomplete is like that seen on the top of Long Hill, the chief difference here being that the planes of schistosity trend northward, parallel to the veins, while at Long Hill they trend nearly eastward, at a high angle to the veins. In the Glasgo locality, and likewise south of Long Hill, large pegmatite masses are associated with the quartz veins. In these cases, however, the comb structure is absent.

The data at hand warrant the conclusion that Lantern Hill was formerly a granitic mass, which has been converted into quartz by an alteration of the minerals in the granite, and by the addition of silica from quartz-bearing solutions entering the rock. The solutions laden with quartz might have entered the granite prior to the time when jointing was produced, and a formation of quartz veins might have been the final stage of the process by which the pegmatite lying south of the hill was intruded. It seems more probable, however, that the heated waters carrying quartz entered the region after joints had been developed, and that the joints afforded access to the ascending solution. This theory is borne out by the fact that the veins are not ruptured, and that they follow the direction of jointing. It is believed that the solutions ascended through the joints and minor fractures of the shattered rock and impregnated the solid fragments, dissolving the bases from the feldspar and depositing silica. Where replacement was complete, the alumina and iron must also have been carried away. The subsequent percolation of ground water would tend to carry mechanically the kaolin through the porous rock, and, where exposed, the kaolin would be quickly carried away, leaving almost pure quartz grains. An analysis of the rock from Lantern Hill showed about 98% of silica. The few scales of micaceous matter present may be an original constituent of the aplite, or a secondary product formed by the action of the heated solution on the original feldspar.*

* For a different explanation of Lantern Hill, see Kemp, in *Trans N. Y. Acad. Sci.*, Aug. 3, 1896.

Willimantic Gneiss [25].— With the city of Willimantic as a center, and extending about four miles in all directions, there is an area of gneiss consisting of alternating dark and light bands. This formation is well exposed in the river at Willimantic, and has been used in building the dams and mills in this region. The boundary of the gneiss has been drawn arbitrarily, and the entire formation might be considered as the more granitic part of a wide area of schistose gneiss. In general the rock is coarse-grained and oftentimes even porphyritic in structure, usually considerably crumpled and folded. In the quarries about Willimantic two varieties appear, called respectively the light and the dark "stock." The dark variety has relatively a small amount of feldspar and quartz, with a large amount of biotite and some hornblende. The light stock is granitic in texture, and contains quartz, feldspar, and biotite in proportions of normal granite. The porphyritic variety seems to have been produced by the injection of quartz and feldspar, much after the manner of the Putnam gneiss; and, indeed, parts of the Willimantic gneiss present the pseudo-conglomerate appearance possessed by the Putnam. Pegmatite veins are found in this formation; also veins of coarse, reddish granite, such as was formerly obtained from the Stone Hill quarry. There is little evidence in the field to indicate the origin of the Willimantic gneiss, but it is considered as the more injected part of the surrounding schists.

Hebron Gneiss [26].— The Hebron gneiss forms an irregular band almost completely enclosing the Willimantic gneiss. It begins as a narrow belt running through Eastford, Ashford, and Mansfield, and increases in width to five miles through Coventry and Andover; it continues south through Hebron, Marlboro, Chatham, and East Haddam; thence eastward through Colchester and Lebanon. Typical exposures are found south of Coventry village, east of Gilead, in the vicinity of the Lyman viaduct, and at Moodus.

Throughout its entire extent the Hebron gneiss shows a great variety of character in both the composition and the

structure of the rock. It varies from granitic gneiss to highly fissile schist, and it is only when the whole area is taken into account that the term gneiss seems appropriate. Where typically developed, as at Moodus and Coventry, the rock is a fine-grained gneiss, with usually a relatively small amount of feldspar. The biotite is often altered to chlorite, and in places has a purplish tinge; it often gives the whole rock a peculiarly silky luster. The rock weathers readily; and a large amount of quartz is present, which, on exposed surfaces, gives it the appearance of sandstone. Quite generally the rock contains small quantities of pyrite, which, on decomposition, exhibits in places a sulphur-yellow color, and is called locally "sulphur rock." Along its western and northern borders the Hebron gneiss grades into the Brimfield schist, and occasionally contains bands of sillimanite schist. Where the formation approaches the Willimantic gneiss, it is apt to be much more gneissoid in character and much more highly feldspathic. Beds of gray gneissoid granite occur as intrusions in the Hebron gneiss, and areas of porphyritic granite are frequently present. Pegmatite veins—large and small—are of common occurrence in the rock, particularly toward the southwest. In Hebron small areas of muscovite-garnet granite are found as intrusions. In this formation, taken as a whole, intrusions of amphibolite are comparatively rare, but they nevertheless occur, as also do seams of light green, fine-grained pyroxene rock. The Hebron gneiss grades into the Willimantic gneiss on one side and into the Scotland and Brimfield schists on the other; thus the boundary lines of the formation are not to be considered as separating rock of completely different character.

Scotland Schist [27].—This formation covers the town of Scotland, and extends southward through Franklin to Bozrah. From this town it extends westward, occupying a large part of Colchester and East Haddam. The Scotland schist is a coarse muscovite schist, squeezed into minute folds as the result of metamorphism. It consists practically of a mass of muscovite, with some biotite, and occasionally garnet and quartz. The quartz usually occurs in seams or

lenses an inch or less in width, and with it are associated small quantities of chalcopyrite. Rarely specimens of Scotland schist are found which contain sillimanite, the characteristic mineral of the Brimfield schist. The Scotland schist does not commonly possess stringers and bosses of granite, though isolated outcrops of a gneissoid granite occur. It is, however, full of pegmatite veins of all sizes, as may be seen in exposed ledges, and, even more plainly, in the abundance of pegmatite bowlders scattered through the southern part of Scotland. The railroad cut east of Pautipaug Hill shows the schist filled with large and small pegmatite veins, usually interbedded, and a gray gneissoid granite underlying it. The western extension of this formation in Colchester and East Haddam exhibits much of a fine-grained biotite gneiss which forms the characteristic rock in the Hebron gneiss, and it seems probable that the Scotland and Hebron grade into each other. It is believed that the Scotland schist is older than the Willimantic gneiss, and probably conformable with the Putnam gneiss to the east.

Canterbury Granite-gneiss [28].— The entire area of the crystalline metamorphic rocks on the east side of the Triassic is injected by granite, either massive, or developed as gneiss. Usually the intrusions are small dikes or lenses. The Canterbury granite-gneiss, however, is a larger area, and extends for a distance of fifteen miles through Pomfret, Brooklyn, Hampton, and Canterbury. Smaller detached areas occur farther south in Sprague, Franklin, and adjoining towns. This formation consists essentially of a muscovite-biotite gneiss varying from a rock of fine and even grain to one of porphyritic texture, with feldspar crystals a quarter of an inch in length. Metamorphism has produced irregular wavy bands of biotite, separated by flattened layers of quartz and feldspar. At the " Wolf Den " in Pomfret the rock is somewhat schistose, and in other places it grades into a true mica schist. In the region of Westminster it has been quarried, and seems to be quite suitable for flagging and rough stonework.

Middletown Gneiss* [29].—Between the Bolton schist and the Haddam gneiss is an irregular band of rock which should be separated petrographically from the area of Haddam granite-gneiss which it almost surrounds. This is the Middletown gneiss, called by Percival the "anthophyllitic formation," and represented by him as completely encircling the Haddam area. The formation is not marked by any one petrographic type, but by a variety of different rocks. One general characteristic is the presence of hornblende in small grains, or more usually in long prisms or stellar aggregates of prisms. A granulitic structure is another feature which many of the rocks possess, and the outcrops quite generally present an unusually rusty color on the weathered surface. There is, however, a variety of types even in the same outcrop.

The dominant type of rock is a hornblende gneiss thoroughly injected with amphibolite and granitic seams and lenses. The rock where least injected is a fine-grained, light gray to greenish, thin-bedded gneiss which has the following mineralogical composition: — a granulitic base of orthoclase, plagioclase, and quartz, in which lie blades and irregular prisms of hornblende. There is some biotite, and a little titanite, garnet, magnetite, chlorite, and apatite. Tremolite occurs in some slides. The black, thin-bedded variety of gneiss, with well developed schistosity, is a typical amphibolite, and is believed to be intrusive. The origin and age of the Middletown gneiss, and its relation to the other formations, have not been determined, but it seems probable that this heterogeneous group of rock types represents the contact zone between the Haddam granite-gneiss and the surrounding formations. So abundant are the pegmatite intrusions in this area that the top of Bear Hill shows almost no other rock exposed.

Maromas Granite-gneiss† [30].—The Maromas granite-gneiss occupies both sides of the Connecticut River, forming

* See note on page 115.

† See Westgate, *A Granite-gneiss in Central Connecticut*, in *Journal of Geology*, vol. VII, p. 638.

an oval area, with a narrow arm extending northward. The rock exposed in the Maromas quarries is a biotite gneiss of medium to fine grain, varying in color with the amount of biotite present. It is massive in some places, but usually well foliated, and the presence of joint planes parallel with the foliation gives the rock a bedded appearance. The composition of the gneiss as revealed by the microscope is orthoclase, an acid plagioclase, quartz, biotite, microcline, with accessory titanite, magnetite, apatite, and rarely hornblende. There is evidence of a slight amount of crushing. Frequently, as along the northeastern border of this area, this formation becomes a decided "augen-gneiss," with sub-porphyritic aggregates of white and pink feldspar averaging three-quarters of an inch in length. The *augen* sometimes show pink cores with white rims. It seems probable that these cores are parts of the original crystallization of the rock, and that the gneissoid structure was in part produced before the rock was completely solidified. With the exception of the presence of *augen,* this variety does not differ mineralogically from the type shown in the Maromas quarries. Lenticular and linear patches of dark colored rock (*schlieren*) are common in the gneiss, and are composed of the same minerals and have the same structure as the lighter gneiss, except that hornblende replaces quartz. A granulitic facies is developed for a mile along the western border and for a somewhat greater distance about its southern end. This is a fine-grained, light gray or brownish rock of sugary texture, composed of orthoclase, plagioclase, microcline, quartz, and usually garnet. The granulite does not have the character of a crushed granite, but seems to be an endomorphic modification of the granite gneiss in contact with the surrounding rocks. Granulite occurs also with pegmatite veins and as dikes in the granite gneiss.

The Maromas granite-gneiss is eruptive and intruded into the Bolton schist, as is shown by the following facts: — the gneiss often cuts across the foliation of the schist and sends tongues into it, and the contact is frequently irregular; fragments and sheets of the surrounding schist, often with

the minute crumplings intact, occur as inclusions in the gneiss.

Extending from a mile below Middle Haddam to South Glastonbury is a belt of rock about a quarter of a mile wide, which is quite different in field appearance from the typical Maromas gneiss. Very dark biotite gneisses and amphibolites are characteristic of this area. Some of these more basic rocks seem to be part of the original molten mass, but many of the amphibolites are later intrusions. So abundant are these hornblendic eruptives that no attempt is made to distinguish them on the map. Pegmatite veins, mostly from a few inches to ten feet in width, occur abundantly in the gneiss.

Haddam Granite-gneiss [31].—This granite-gneiss occupies an area, triangular in form, with its base near the Sound and its apex on the Connecticut River north of Higganum, and forms a large part of the country between the Sound, the river, and the eastern border of the Triassic sandstone.

The typical rock of the area is well exposed about Higganum on both sides of the Connecticut. It is a light colored, rather fine-grained granitic aggregate of quartz and feldspar, through which are scattered small isolated flakes of biotite, which give an indistinct foliation to the rock. Hornblende is sometimes present in addition to the biotite. Plagioclase is present, but is less abundant than the orthoclase. Small garnets are common. In most of the outcrops the rock is a moderately thick-bedded gneiss, and usually crumbles readily on weathered surfaces.

About a half-mile inside the northern boundary of the area, and with a direction roughly parallel to its border, is a belt of hornblende gneiss and amphibolite, which separates the granite-gneiss described above from a belt of darker, thinner-bedded gneisses, which are at a number of places quarried for flagstones, and which comprise the outer zone of the Haddam gneiss. This belt of hornblende gneisses cannot be traced for more than a mile from the river either to

the west or east, and the difference in the granitic gneisses north and south of it is probably merely a local variation, without stratigraphic importance. This flagstone facies of the Haddam is well shown in the small quarries near the river two miles north of Higganum. The rock is a dark gray, quite micaceous, well foliated gneiss. Hornblende is usually present, but in less amount than the biotite, though in one or two localities it is the more abundant of the two minerals. Orthoclase is more abundant than plagioclase. Quartz is present, and magnetite, apatite, and garnet occur in small quantities as accessories.

At Walkley Hill a hornblendic rock occurs in the Haddam granite-gneiss, in the same relative position as the band farther north, and is possibly the continuation of that band. West of the river, to the north, this amphibolite can be traced for nearly a mile. The strike of the foliation or banding in the northern part of the Haddam gneiss is parallel with the border of the formation. The dip is everywhere toward the border. From its composition and field relations it is inferred that the Haddam gneiss is probably of igneous origin.

Branford Granite-gneiss [32].— This gneiss occupies a narrow area along the shore of the Sound, extending from Lighthouse Point on the east side of New Haven harbor, to Haycock Point some twelve miles farther east. On the north it is bounded by the Triassic sandstone. and Middletown gneiss, while the Stony Creek granite-gneiss forms the eastern boundary. Its area is about twelve square miles. The best exposures are in the railroad cut, a half-mile west of Pine Orchard station. The rock is a medium-grained granite, with a banded structure, consisting very largely of white feldspar. In the feldspars are imbedded small round quartz grains, having a slightly brownish tint, and biotite is present in about equal amount. Small reddish garnets are commonly found in the rock, though at times they may entirely fail. The rock throughout has a pronounced tendency to weather with a brownish stain on the cleavage surfaces of the feldspar. It is strongly injected with pegmatite; and

in places evident traces of a gneiss infolded in the granite and pegmatite are to be seen, as along the shore between Pine Orchard and Indian Neck. The gneissic structure of the rock is not uniform; at some localities, as at Lighthouse Point, it is quite indistinct, and the rock has much the appearance of a true granite. Jointing in the rock is pronounced at all points, especially in the western portion.

Stony Creek Granite-gneiss * [33].— The principal area covered by this rock is roughly semicircular in outline, extending a distance of six miles along the shore from Haycock Point to West River in Guilford. Its most northern point is about three and one-half miles inland. A much smaller area is found in the vicinity of Clinton. The rock presents some diversity of type, but in general may be described as follows:— a rock of grain medium to coarse, composed very largely of flesh-colored to pink orthoclase crystals, with white albite, small gray quartz grains, muscovite, and biotite in subordinate amounts. Under the microscope, in addition to the above minerals, small magnetite, apatite, and zircon crystals are seen to be present. The red tone of the rock is due to the predominance of the orthoclase over all other minerals. Variations in appearance are due to differences in the size of the crystals composing the rock, which, although generally medium-grained, is sometimes much coarser, and more rarely considerably finer, than the common type. Differences in the amounts of the red and white feldspars, and different degrees of segregation of the biotite, also cause noticeable variations in appearance.

In larger masses the rock commonly displays a banded structure, due to the fact that the different minerals are separated more or less completely from one another in narrow layers, ranging from a minute fraction to a half-inch in thickness. At many points, also, the pink orthoclase layers show lens-shaped enlargements, which are proved by the microscope to be larger crystals (phenocrysts) or groups of

*The granite-gneiss and related formations of the Stony Creek district were studied by Dr. W. E. Ford, while associated with Professor Gregory in work for the U. S. Geological Survey. The description here is based largely on his work.

crystals somewhat crushed and drawn out. It is certain that the rock at some localities, especially at Hoadley Point, has been greatly squeezed. This is obvious to the eye, and further evidence is obtained from thin rock sections when studied with the microscope. There is considerable fine-grained red, rarely gray, granite and pegmatite associated with the Stony Creek granite-gneiss, cutting it as veins. The pegmatite is also developed as small coarse-grained areas in the normal rock. The composition of these later veins is the same as that of the country rock, with the addition of occasional pyrite crystals. Pegmatite veins are most common near the border of the area, the great majority of them lying within a marginal zone a half-mile wide. There are also associated with this formation small included masses of a biotite-hornblende gneiss. The relations of the two rocks are well shown in the railroad cuts. There the gneiss above mentioned, cut by veins of the Stony Creek granite-gneiss, and even entirely surrounded by it, furnishes clear proof that the granite-gneiss is intrusive and younger than the biotite-hornblende gneiss.

The granite-gneiss is decidedly broken by faults and joint planes. Certain of these joints (most obviously a series of horizontal ones) are probably due to the partial relaxing of stresses originally present in the mass when deeply buried; others are due to later crustal movements which extended over the entire state. In general the rock is too broken to be of great value for quarrying, although there are a number of localities where it is sufficiently massive to make good building material.

Lyme Granite-gneiss * [34].— The area occupied by this formation is of irregular shape, covering portions of the towns of Lyme, Old Lyme, and East Lyme. The boundary between it and the Mamacoke gneiss is fairly well marked in Old Lyme and East Lyme. The boundary on the north is less satisfactory, on account of the confused manner in

* The geology of southern Connecticut from Saybrook to Mystic was studied by Dr. H. H. Robinson during the summer of 1904. The descriptions of the Lyme and New London granite-gneisses and of the Mamacoke gneiss were written by him.

which this rock has broken through the Mamacoke gneiss, and also on account of the extensive covering of Glacial till. The best exposures are found along the Connecticut River north of Lyme, on the north and west sides of Rogers Lake, and at the quarry on Rocky Point near South Lyme. At those localities the rock is massive and of medium grain; the color is generally light red, shading to gray. It is composed essentially of pink orthoclase, quartz, and albite, with a small, though somewhat variable, amount of biotite, and occasional crystals of hornblende. The gneissic structure of the rock is well developed throughout the area, especially in the more northern portions. There is considerable pegmatite associated with the granite-gneiss, in the form of coarse-grained veins and spots in rock of normal grain. Outcrops of the pegmatite appear more numerous in the southern parts of the area and especially near the boundary. Its composition is quite the same as that of the country rock. In texture it is granitic with only occasional suggestions of banding. The pegmatite, as well as the granite-gneiss, is well exposed in the Luce quarry on Rocky Neck.

New London Granite-gneiss [35].—The rock included within this area, which has been marked off from the Mamacoke gneiss by a rather arbitrary boundary, is distinctly granitic in character. Typical exposures in and about New London exhibit a light gray, rather fine-grained rock of uniform texture, composed largely of feldspar and quartz with subordinate brilliant black biotite and occasional hornblende crystals. At some exposures a few small garnets may be found. On account of the small amount of biotite, the gneissic structure is less pronounced than in the rocks containing more of that mineral. Outcrops about one mile west of New London on the road to Jordan Village are streaked with veins and nodules of pinkish feldspar, which is sometimes intergrown with quartz in the manner of graphic granite. Seams and patches of a dark colored biotite gneiss are here seen, included in and cut by the granite-gneiss. The rock of this formation is generally firm in texture, and is quite largely used locally for the foundations of buildings.

Mamacoke Gneiss [36].— From Guilford to the Connecticut River this gneiss occupies an elongated area, one to four miles in width, bounded on the north by the Middletown gneiss and on the south by the Stony Creek granite-gneiss, and by the Sound. From Essex it extends northward to Chester. It then turns eastward; and, gradually spreading out, occupies the greater parts of the towns of Salem, Montville, Waterford, and Groton, with lesser portions of Lyme, East Lyme, East Haddam, Ledyard, Stonington, and North Stonington. A small detached area is found in the southeastern part of Old Lyme. The rocks occupying the larger area are in some localities decidedly gneissic, containing much biotite and more rarely hornblende, but elsewhere they are very granitic in appearance. These different types of rock are probably of different age, and possibly of different origin; but much work in the field will be necessary to separate the several varieties and determine the many questions that they suggest.

In that portion of the area west of the Connecticut River the predominant rock is uniformly medium-grained, light to dark gray in color, and consists of white feldspar and quartz, with brilliant black mica, and sometimes small amounts of hornblende or garnet. In typical specimens the dark minerals constitute about one-third of the mass; but the range in both directions is considerable, giving rise in one case to a biotite gneiss, in the other to a granitic gneiss. Throughout the area the banding of the rock is plainly evident on account of the contrast in color between the layers of white feldspar and quartz and those of black biotite. The rock for the most part appears fresh and firm in texture. It has been used locally for building purposes; and, where the structure permits, it has been quarried for flagging. This gneiss is typically developed in the vicinity of Horse Hill, northeast of Clinton. Farther east, along the Connecticut River from Saybrook Junction to Essex, the rock is finer-grained and appears to be considerably more altered. There is a noticeable injection of granite into this, as well as into the more typical rock, along a zone beginning at the first outcrops

west of the river opposite Lyme, and extending in a southwesterly and westerly direction for over two miles.

In the region extending from Essex through Deep River and eastward to the vicinity of Salem, the gneiss as a whole is rather more granitic and contains areas of a later granite. Exposures of the typical Mamacoke gneiss occur in and southeast of Deep River and in the northwest corner of the formation in Chester. Elsewhere the rock has a lighter color, due to the presence of a smaller amount of biotite, which also results in a less prominent banding. The tone of the rock is generally brownish — the feldspar being stained by the iron set free by the decomposition of the biotite,— sometimes reddish when pink feldspar is present. The grain of the rock is fine to medium, never coarse. The rock on Selden Neck, opposite Deep River, is quite different from that surrounding it, and is a later intrusion of granite. It is composed largely of pink orthoclase, with small amounts of clear quartz and black biotite. Banded structure is prominent, and the biotite is arranged in more or less parallel lamellæ and lenses rarely over three inches in length.

The larger portion of this area, lying to the east and west of the Thames, consists of an apparently complicated mixture of older gneisses injected and broken by later intrusions. They are for the most part granitic in character; and because of this fact and the pronounced alterations they have undergone at many localities, the work of separating them is of considerable difficulty. The work of one field season was only sufficient to make the above point evident and furnish a basis for future study. We may say, as Percival said in his report, "The first five ranges (east of the Connecticut River) may be regarded as continued in that part of the formation, extending through Montville, Groton, and Ledyard; but I have not been able to trace them there with sufficient distinctness to enable me to discriminate them as in that part of the present section already described."

The exposures in the abandoned quarry about a half-mile south of the United States Naval station, and on

Mamacoke Island opposite the station, are typical of a very large part of the area. At the quarry the exposure may be divided into two parts — the eastern consisting of many alternating bands, usually less than two feet thick, of black biotite and white feldspar and quartz; the western, a normal reddish gray granitic gneiss. Both are strongly folded, as may be seen by inspecting the banded portion of the exposure. In the upper part of the quarry is a dike, two or three feet thick, of fine-grained, gray to faint reddish granite. It is younger than the gneiss, and cuts across it in an east and west direction, descending at an angle of about 25° toward the south. A rock similar to that of the dike is found in small scattered outcrops throughout this region, and is of the same character as that quarried at Westerly, Rhode Island, and at Millstone Point and the Booth quarry in the town of Waterford.

The detached area in Old Lyme shows notable injection by the Lyme granite-gneiss and pegmatite near Black Hall. One small but interesting exposure on the line of the railroad and just east of Mill Creek may be noted. It shows the Mamacoke gneiss cut by coarse red pegmatite, and both the gneiss and pegmatite cut by a small dike of fine-grained biotite granite. Since the pegmatite is always found associated with the granite-gneiss, a certain order of events, confirmed at other localities, may be made out. The Westerly, Waterford, Millstone, and other gray to red, fine-grained granites are intrusive, generally as dikes, in the Stony Creek, Lyme, New London, and Sterling granite-gneisses and in the Mamacoke gneiss; and these granite-gneisses are intrusive, generally as bosses, in the Mamacoke gneiss. What position in geological time to give these three groups of rocks is not evident. One can only say that the differences between the gneiss and granite-gneisses are quite sharply defined, and must represent a considerable interval of time. The pegmatite is, as we have seen, contemporaneous with the granite-gneisses, while the fine-grained granite (Westerly, etc.) may be considered as the final product of the granite-gneiss period of intrusion or as distinctly later than that period.

Preston Gabbro-diorite* [37].— A region of dark colored rock forms a roughly oval area in parts of Preston, Griswold, North Stonington, and Ledyard. In character the rock shows a number of variations, and follows a definite gradation from the center of the mass toward the periphery. The central part in the vicinity of Bay and Rixtown Mountains is a coarse porphyritic gabbro containing phenocrysts often over two inches in length. These larger crystals are set in a ground-mass of labradorite and green hornblende, occasionally accompanied by pyrite and garnet. The coarse gabbro is cut by veins of pegmatite and small dikes. The pegmatite occurs as short veins and lenses, sometimes without distinct borders. Its chief constituent minerals are hornblende and plagioclase feldspar. Quartz occurs in it, but is never abundant. Narrow, short dikes, probably of diabase, cut both gabbro and pegmatite.

Forming a zone around this central mass of gabbro, and exposed on Bay, Lambert, and Rixtown Mountains, is a medium-grained dark rock having the composition of diorite. The mineral constituents are similar to those of the gabbro, but the feldspar is andesine and the hornblende is distinctly crystallized.

At the margin of the mass the rock becomes a quartz diorite. Metamorphism occurs where the igneous mass came in contact with the schists and gneisses of the region, and the resulting heat has converted slates into hornstone. Fragments of hornstone are also found included in the gabbro, and stringers of the igneous rock are seen to enter the schists. Regional metamorphism has produced schistosity in the rocks surrounding the mass, and has affected the border of the quartz diorite zone. The gabbro and diorite masses have been profoundly altered, but they lack the gneissoid structure. The strike of the foliation planes of the surrounding rock follows the borders of the igneous mass, and it appears that the main mass of gabbro-diorite effectively resisted the pressure which resulted in the production of schistosity in the other types of rock.

* See note on page 132.

The data at hand lead to the conclusion that the Preston gabbro-diorite is a bathylith — a deep-seated igneous mass exposed to view by removal of the overlying rocks. When the heated rock invaded the ancient sediments, they were baked and recrystallized as a result of the severe heat. Later, schistosity was developed in this region, but the bathylith was too firm to yield to the pressure which so completely modified the surrounding rocks.

Westerly Granite.— Along the eastern Connecticut shore line and extending into Rhode Island are found a number of exposures of gray and pink granite, which are apparently of the same character and age. This rock is quarried at several places, but particularly at Westerly and Niantic, Rhode Island, just east of the Connecticut line, whence the formation receives its name. Smaller quarries have been opened west of Pawcatuck River in Stonington. Of late years these localities have furnished large quantities of rock for building and especially monumental work.

At Westerly two varieties of rock are quarried:— a finely crystalline, gray rock, which shows minor variations in color and texture, but which is petrographically the same, and which is the Westerly granite of commerce; and a light red coarse granite (the Sterling granite-gneiss), which somewhat resembles the rock from Stony Creek, but is much finer. The small quarries in Mystic and Groton furnish a gray variety, although the rock from the latter place is somewhat coarser than the typical Westerly. The Waterford and Millstone Point quarries yield stone which is almost identical with the Westerly.

Where typically exposed the Westerly granite is massive, with no indication of gneissoid structure; it is, however, cross-jointed and broken into blocks. Quartz, biotite, and a small amount of muscovite are the chief minerals composing the rock, hornblende being entirely absent.* In the Westerly quarries small spots of a black, pitchy material,

* For a petrographic description of the Westerly granite, the reader is referred to a paper by Professor J. F. Kemp, in *Bull. Geological Society of America*, vol. X, pp. 361-382.

probably allanite, occasionally occur, giving the rock the local name of "bedbug granite." The variation in color from red to bluish gray seems to be caused by the variation in degree of oxidation. That oxidation takes place readily is apparent from the fact that fragments discarded from the quarry are pinkish at the surface, while the interior is still gray.

The Westerly granite is of an intrusive nature, and has been thrust into the Sterling granite-gneiss and other formations along the shore line. This rock is seen to send out irregular stringers into the surrounding gneisses, and to contain inclusions of amphibolite and other rocks. The relation between the different rocks of this area seems to be as follows:—the Sterling granite-gneiss is injected into earlier sediments; pegmatites cut the Sterling granite-gneiss; and the Westerly granite is intrusive in pegmatites and granite-gneiss alike, and thus is the youngest formation in the south-eastern part of Connecticut.

The areas of Westerly granite are too small to be shown on a map of the scale of Plate XIV.

Pegmatite.— Pegmatite is widely distributed over the eastern crystallines, and presents no peculiarities which distinguish it from similar rocks in the western part of the state (see page 110). Putnam gneiss, Sterling granite-gneiss, and Scotland schist are especially full of pegmatite veins, but their distribution is scarcely less abundant in the other formations. Certain areas, like the White Rocks south of Middletown and the hill near Leesville, as well as a district south of Lantern Hill, contain unusually large and unusually abundant pegmatite masses. For a description of the nature of pegmatite the reader is referred to page 71.

Amphibolite [38].— As indicated in the descriptions of the various formations, amphibolite is abundant in the eastern part of Connecticut. Its composition and mode of occurrence are identical with those of the amphibolite of the western crystallines (see page 112).

Diabase Dikes [39].— Intrusions of diabase in the form of dikes are an even more common feature in the crystallines of the eastern portion of the state than in those of the western.* The dikes are not distributed in haphazard fashion, but form two belts, one extending from Manchester to West Stafford, and the other constituting a remarkable series extending from Branford northeastward to Union, a distance of probably seventy miles. In some places the dikes are prominent topographic features, but usually they present no conspicuous surface forms, and it is a testimony to Percival's great skill as a field observer that he was able to trace the dikes and connect the inconspicuous scattered outcrops. In general the texture and composition of the dikes on the eastern side of the Triassic area are identical with those along the Housatonic, but there is apparently a greater amount of crushing and more alteration of the constituent materials. These dikes are believed to be of the same age as the Triassic sedimentary strata with their accompanying traps.

* For a description of the Triassic intrusions of the western crystallines see page 113.

Chapter III

The Triassic

By
WILLIAM NORTH RICE

THE TRIASSIC.

HISTORICAL REVIEW.

In these brief historical notes it is not proposed to mention all the geologists who have done valuable work in the study of the formation in question. Still less is it proposed to give a complete bibliography of the subject. There is less need of this, in view of the fact that a very full and accurate index to the literature of the subject prior to 1892 is given in Professor I. C. Russell's "Correlation Paper" on the Newark System, published as Bulletin No. 85, of the United States Geological Survey. While some important observations were made at an earlier date by the elder Silliman and others, the systematic study of the Connecticut Trias commenced with the appointment of J. G. Percival as State Geologist, in 1835. His report was published in 1842. That report was an admirable piece of work, as regards the conscientious thoroughness with which the local distribution of the various kinds of rocks was described. The science of dynamical geology was then too little developed to afford a basis for any satisfactory interpretation of the facts, and Percival seems to have chosen almost entirely to refrain from any intimation of theoretical interpretations, if he had any such in mind. Professor J. D. Dana, who held so long an honored place at the head of American geologists, devoted considerable time to the study of the Triassic formation as exhibited in the immediate vicinity of New Haven. His latest views may be found in his little book "On the Four Rocks of the New Haven Region," published in 1891, and in his "Manual of Geology," of which the latest edition was published in 1895. Professor Dana was led into error in regard to the relations and history of the trap rocks of the area by the assumption that inferences drawn from the trap hills in the immediate vicinity of New Haven could be ex-

tended without qualification to other parts of the area. He was undoubtedly right in the judgment that the trap of East and West Rock is intrusive, but he failed to appreciate the evidence adduced by Davis and others proving the very different relations of the line of trap ridges in the middle of the Connecticut Valley area. To Professor W. M. Davis, more than to any other man, is due the correct interpretation of the relations of the sandstones and the associated trap rocks of Connecticut. His studies in the region commenced in 1882, and were continued for several years, the latter part of the time under the auspices of the United States Geological Survey. A number of geologists served as assistants in this investigation, among whom were C. L. Whittle, E. O. Hovey, H. B. Kümmel, W. N. Rice, S. W. Loper, and L. S. Griswold. The latest of Professor Davis' Papers, giving in most complete form the results of the whole investigation, was published in 1897, in the Eighteenth Annual Report of the United States Geological Survey. That paper is by far the most important work for the student of this formation in Connecticut. In 1901 Professor W. H. Hobbs published a valuable paper on "The Newark System of Pomperaug Valley," in the Twenty-first Annual Report of the United States Geological Survey. This paper gives the fullest account of the curious little area of the Triassic formation in the towns of Woodbury and Southbury.

The Connecticut student will of course be interested in the investigations which have been carried on in the more northerly portion of the Connecticut Valley area, lying in the State of Massachusetts. Substantially contemporaneous with the investigations of Percival in Connecticut were those of Edward Hitchcock in Massachusetts. His "Final Report on the Geology of Massachusetts" was published in 1841. In later times the study of the Triassic of Massachusetts has been carried on with great zeal and ability by Professor B. K. Emerson. His "Geology of Old Hampshire County" was published in 1898, as Volume XXIX of the Monographs of the United States Geological Survey. Parts of the Connecti-

cut Valley area are mapped in detail, with explanatory text, in the Holyoke Folio of the Geologic Atlas of the United States, by B. K. Emerson, and in the Farmington Folio by H. E. Gregory.

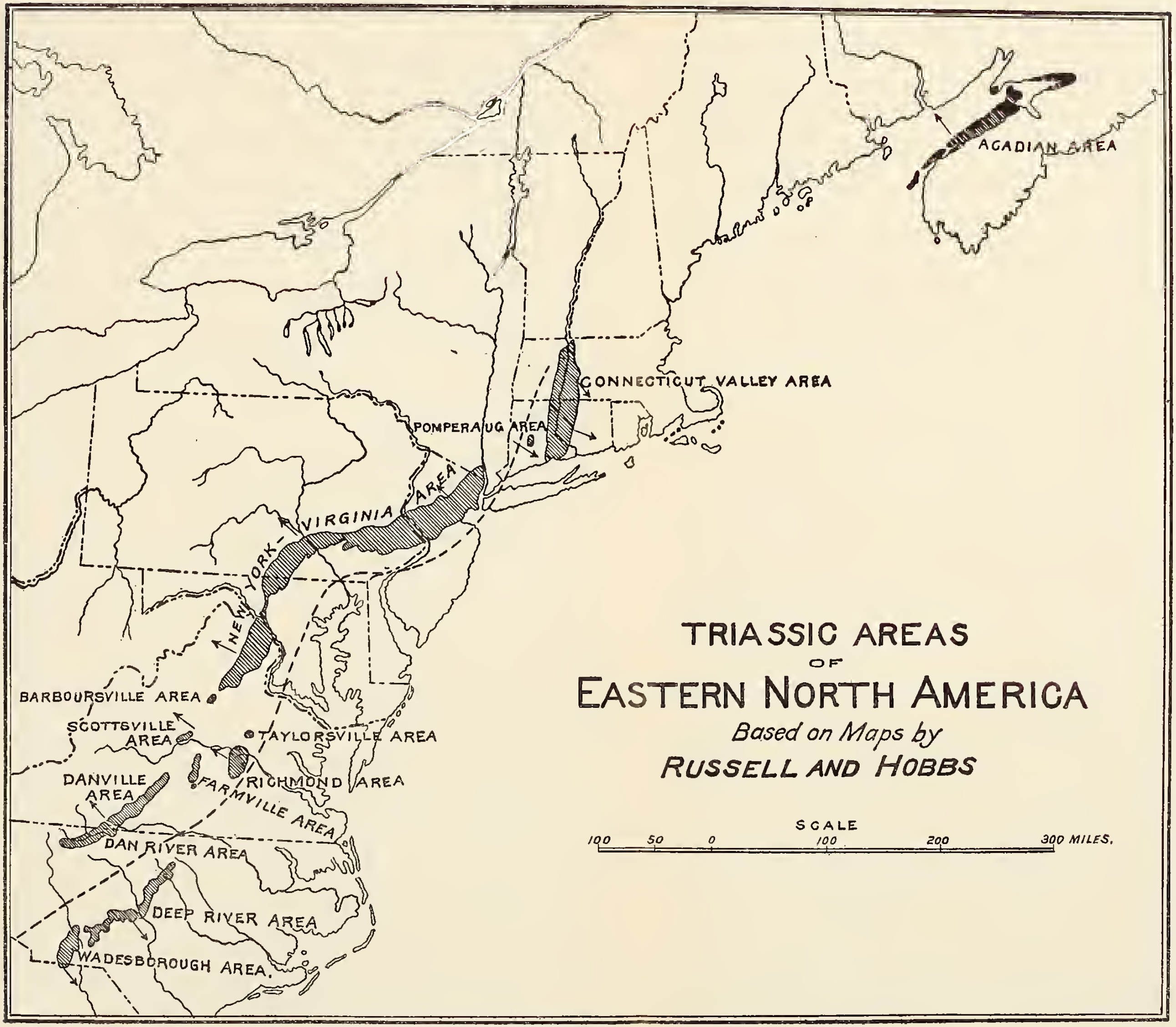
Much light has been thrown upon the Triassic formation of Connecticut by the study of the contemporaneous formations in other parts of the country. Much valuable work has been done by the Geological Survey of New Jersey. Two papers may be commended to the student as of special value in regard to the Triassic formation in New Jersey; namely, Kümmel's "The Newark System of New Jersey," in the Annual Report of the State Geologist of New Jersey for 1897, and Darton's "The Relations of the Traps of the Newark System in the New Jersey Region," published as Bulletin No. 67 of the United States Geological Survey. On the more southerly areas of the Triassic formation, the most important paper is Shaler and Woodworth's "Geology of the Richmond Basin," published in the Nineteenth Annual Report of the United States Geological Survey. Professor Russell's paper already referred to gives an admirable summary of the results of the study of all the Triassic areas of eastern North America down to 1892.

A few works may well be mentioned bearing especially upon the fossils of the formation. Hitchcock's "Ichnology of Massachusetts" gives the results of the author's patient and earnest study of the tracks of animals on the sandstones, of which he had accumulated a magnificent collection in the museum of Amherst College. For a later revision of the study of these tracks, in the light of present knowledge of paleontology and comparative anatomy, the student may be referred to a memoir by Professor R. S. Lull on the "Fossil Footprints of the Jura-Trias of North America," in the fifth volume of the Memoirs of the Boston Society of Natural History. The fossil fishes are described in Newberry's "Fossil Fishes and the Fossil Plants of the Triassic Rocks of New Jersey and the Connecticut Valley," published as Volume XIV of the Monographs of the United States Geological Survey. A more recent review of the fossil fishes, by

Dr. C. R. Eastman, is found in the Annual Report of the State Geologist of New Jersey for 1904. For the plants of the formation reference may be made to the above cited work of Newberry, and also to Fontaine's "Contributions to the Knowledge of the Older Mesozoic Flora of Virginia," published as Volume VI of the Monographs of the United States Geological Survey.

THE STRATIFIED ROCKS.

Areal Distribution.— The Triassic formation in eastern North America is represented by deposits of essentially similar type distributed in isolated areas from Nova Scotia to North Carolina. The principal areas are the following (see Plate XV):— 1, Acadian area; 2, Connecticut Valley area; 3, Pomperaug Valley area; 4, New York-Virginia area; 5, Barboursville area; 6, Scottsville area; 7, Taylorsville area; 8, Farmville area; 9, Richmond area; 10, Danville area; 11, Dan River area; 12, Deep River area; 13, Wadesboro area. Besides these there are a number of small patches of the formation in question, which are obviously outliers of the larger areas separated from them by erosion. The Acadian area lies chiefly in Nova Scotia along the southeastern shore of the Bay of Fundy. It includes, however, some small isolated patches in the adjacent part of New Brunswick. The Connecticut Valley area extends from near the northern boundary of Massachusetts to New Haven in Connecticut. The course of the Connecticut River from Turner's Falls, Massachusetts, to Middletown, Connecticut, lies in this Triassic area; but from Middletown to Saybrook the Connecticut River flows in a gorge which it has carved through the older crystalline rocks. The Pomperaug Valley area is a small area drained by the Pomperaug River, lying in the towns of Woodbury and Southbury, Connecticut. This area and the southern part of the Connecticut Valley area are shown in the map, Fig. 1, page 19. The New York-Virginia area is the most extensive continuous area of Triassic rocks in eastern North America. Beginning on the west bank of the Hudson at the Palisades, it extends in a


AGADIAN AREA
CONNECTICUT VALLEY AREA
POMPERAUG AREA
NEW YORK–VIRGINIA AREA
BARBOURSVILLE AREA
SCOTTSVILLE AREA
TAYLORSVILLE AREA
DANVILLE AREA
RICHMOND AREA
FARMVILLE AREA
DAN RIVER AREA
DEEP RIVER AREA
WADESBOROUGH AREA.
TRIASSIC AREAS
OF
EASTERN NORTH AMERICA
Based on Maps by
RUSSELL AND HOBBS
SCALE
100 50 0 100 200 300 MILES.

general southwesterly direction, but in a sinuous curve convex to the southeast at both ends, but convex to the northwest in the middle, across New Jersey, Pennsylvania, and Maryland, into Virginia. The Barboursville, Scottsville, Taylorsville, Richmond, and Danville areas are all situated within the state of Virginia. Of these the most extensive are the Richmond and the Danville area. The Dan River area lies chiefly in North Carolina, and the Deep River and the Wadesboro area are entirely within that state. Wells bored through the later strata have revealed the presence of the Triassic rocks beneath the surface in South Carolina, but nothing definite is known of their extent.

Kinds of Rocks.— The rocks in all these areas would naturally be characterized in a broad way as red sandstones. The sandstones, sometimes coarse, sometimes fine, consist mainly of grains of quartz, feldspar, and mica, resulting from the disintegration of the older rocks which form the walls of the troughs in which the sandstones were deposited. The prevailing red-brown colors of the sandstones are due not to the constituent grains, but to the cementing material, which contains a large amount of ferric oxide.* These sandstones have been much used as building stones. In large and massive buildings they have an imposing effect, though the dark color is thought by some to make their aspect rather somber. When care is taken to place the blocks in a wall with the lamination horizontal, the stone proves very durable. When the rocks are laid with the lamination vertical and parallel to the face of the wall, the action of frost often results in the peeling off of the outer layers.

These sandstones have been extensively quarried in Portland, Fair Haven, and Manchester; and small quarries, chiefly for local supply, have been opened in numerous other places.

The following analysis of the sandstone from Portland is taken from Professor Gregory's paper in the Farmington Folio of the United States Geologic Atlas:—

* For discussion of the origin of this ferruginous material, see Russell, *Subaerial Decay of Rocks* (*Bull. U. S. Geological Survey*, No. 52), p. 44.

SiO_2	70.11
Al_2O_3	13.49
FeO and Fe_2O_3	4.85
MnO	.35
CaO	2.39
MgO	1.44
Na_2O, K_2O, H_2O	7.37
	100.00

While the name sandstone would properly express the prevalent and typical character of the rocks of the formation, the material is in some strata so coarse as to deserve the name of conglomerate, and in others so fine as to deserve the name of shale. In the conglomerates, the pebbles may be less than an inch in diameter, but they are sometimes much coarser. In some localities occurs a rock which has been called "giant conglomerate," in which some of the bowlders are several feet in diameter. The conglomerates occur chiefly near the borders of the Triassic areas, and in these it is especially easy to recognize the rocks from the disintegration of which the pebbles have been derived. In general, it may be said that the pebbles in any particular area are derived from rocks in the immediate vicinity. The conglomerates in the Connecticut Valley area are obviously derived from the gneisses, schists, and pegmatites, which are the prevalent rocks of the Eastern and Western Highlands. In some cases, however, it has been observed that the pebbles of the conglomerates are derived from rocks which are found *in situ* not immediately adjacent to the locality of the pebbles, but at a distance of a number of miles. This may indicate that the waters in which the conglomerates were deposited were traversed by currents, tidal or otherwise, of considerable force.* In some cases, however, the dissimilarity between the pebbles in the marginal conglomerates and the rocks *in situ* in the immediate vicinity is doubtless due to the presence of faults.† The frequent oc-

* Emerson, *Geology of Old Hampshire County*, pp. 355, 374.

† Kümmel, *The Newark System of New Jersey*, in *Ann. Rep. State Geologist*, 1897, p. 56.

currence of faults at the border of the formation will be discussed later.* The beautiful calcareous breccia called Potomac marble is a conglomerate occurring in parts of the New York-Virginia Triassic area derived from the disintegration of limestones which formed a part of the wall of the trough.

The shales, like the sandstones and conglomerates, are prevailingly red, owing their color likewise to the presence of ferric oxide. Some strata of shale, however, contain in considerable quantity hydrocarbon compounds derived from the decomposition of organic matter. These bituminous shales are accordingly nearly black. In the Connecticut Valley area, there are two thin strata of these bituminous shales, which have been shown, by careful search for outcrops, to have a very wide extent.† One of these lies between the anterior and the main sheet, and the other between the main and the posterior sheet of contemporaneous trap, which will be subsequently described.‡ A few outcrops of the black shale have been observed, which appear to indicate at least local deposits at a still higher horizon. At several localities fossil plants and fishes are abundant in these shales.§ In connection with these black shales are found thin films of coal. It is, however, safe to say that no coal beds of workable extent will ever be found in the Triassic formations of Connecticut. In the Connecticut Valley area the strata dip somewhat uniformly to the east, and the edges of the whole series of strata are exposed by erosion. The deepest and oldest strata, therefore, crop out near the western border of the formation. Strata of coal of sufficient thickness to be of commercial value would certainly have been discovered in the thorough study which has been given to this formation. To make expensive borings in search of coal is a foolish waste of money. While no workable beds of coal have been found in any of the northern Triassic areas, such beds have been found in the Richmond, Farmville, Dan River, and Deep River areas. Besides the films of coal

* Page 213.

† Davis and Loper, in *Bull. Geological Society of America*, vol. II, p. 415.

‡ Page 186.

§ For mention of localities, see paper of Davis and Loper above cited.

found in Connecticut with the black shales, fragments of lignite are occasionally found scattered through the sandstones. It is an interesting fact that the sandstones containing these fragments of lignite are not red, but gray or white, the ferric oxide having been reduced by the decomposing vegetable matter.

A small amount of impure limestone is also included in the Triassic formation of Connecticut. A thin stratum has been recognized in several localities lying a little above the anterior sheet of contemporaneous trap.

Conditions of Deposition.—The Triassic formations of eastern North America appear to be estuarine rather than marine in origin. The prevailing red color of the rock indicates other than marine conditions. The exuberance of life in the shallow waters of the seashore usually affords so much decomposing organic matter as to reduce any ferric oxide which may be present. Red sandstones and shales in general indicate estuarine or lacustrine rather than marine conditions. This indication afforded by the rock itself is confirmed by the character of the fossils, of which more will be said later.* Here it may simply be remarked that (with the exception, apparently, of a very few molluscan shells) no marine fossils have been found in any of the Triassic formations of eastern North America, but only remains of fresh-water and terrestrial life.

One of the most obvious conclusions in regard to the rocks is that they were deposited in shallow water. The thick beds of sandstone often show oblique lamination in varying directions. This indicates that the sands were swept along by changing currents. That is exactly the condition which would exist in a tidal estuary. Many of the layers have their surface marked with the alternation of ridge and furrow known as ripple-mark. Whether this structure is due to the oscillation of the water at the bottom in connection with waves at the surface, or to currents in the water heaping up the sand as in miniature dunes, it is certain

* Page 170.

that it can be formed only in comparatively shallow water. Other markings frequently found on the surface of the layers show that the surface was sometimes left bare by receding tides or subsiding freshets before the deposit had consolidated. Such evidence is afforded by the little pits impressed occasionally on the sand or mud by the drops of a short spatter of rain; also by the network of cracks, often rudely hexagonal in their arrangement, formed by the shrinkage of the mud as it dried in the sun. Testimony of the same sort is borne by the tracks of reptiles and other animals that walked over the still soft sands or muds.* A curious coincidence often observed is the radiation of mud-cracks from the tips of the toes of tracks. The obvious meaning is that the drying of the mud had reached the point at which it was just ready to crack, and the disturbance made by the footstep overcame the force of cohesion and so started the crack.

As has been already remarked, the strata of the Connecticut Valley area have a prevalent dip to the east, and the edges of the whole series of strata have been exposed by erosion. It will be seen hereafter that the tilting of the strata was accompanied by a good deal of fracturing and faulting. In a generalized and diagrammatic fashion the present condition of the strata is represented in Fig. 2.

A simple inspection of the figure shows that the area of the original deposit must have been greater than the area of the remnant which has been left by erosion. This at once suggests the question how great we may reasonably suppose the original extension of the formation to have been. The majority of the geologists who have studied the Triassic formation believe that it was deposited in a number of isolated basins, and that the boundaries of the areas of deposition were not many miles removed in any case from the boundaries of the present areas of the rocks. This view substantially has been held by Percival, Dana, Davis, Emerson,

* Many of the specimens of ripple-marks, rain-prints, and tracks, are casts of the original impressions, with the relief exactly reversed, formed on the under surface of the overlying layer.

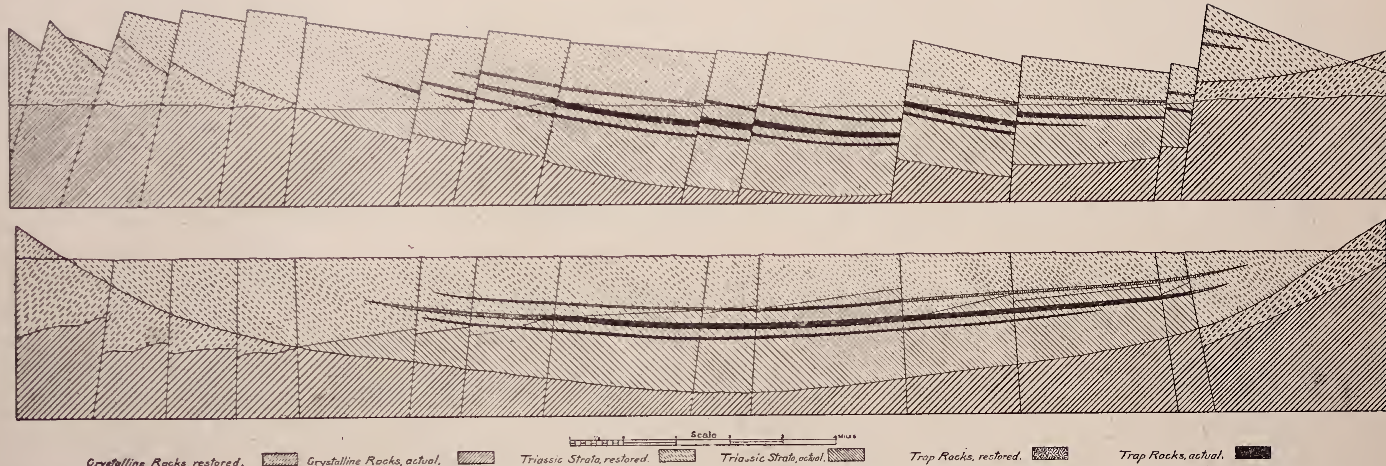


Fig. 2. Sections across the Connecticut Valley Triassic. The upper section shows the present attitude of the formation as tilted and faulted. The parts which have been removed by erosion are restored. The lower section shows the supposed attitude of the formation before the tilting and faulting. (The shading with parallel lines does not represent planes of stratification.) From Davis' paper in *Eighteenth Annual Report of U. S. Geological Survey*.

Newberry, Kümmel, and Shaler.* It has been maintained, on the other hand, by a few students of the formation, particularly by Professor I. C. Russell and Professor W. H. Hobbs, that the Triassic deposit once formed a continuous area from Nova Scotia (or at least from Massachusetts) to South Carolina, which has been broken into discontinuous areas by a vast amount of erosion.† The enormous amount of erosion demanded by this theory seems rather overwhelming to the non-geological reader; but the geologist appreciates so fully the unquestionable fact that vast erosion has taken place in this region, as in many other regions of the earth's surface, that he would find in that requirement no serious objection to the hypothesis in question. There seem to be, however, two somewhat serious objections to the hypothesis that the Triassic sandstones ever formed a continuous area. It is a little difficult to picture any geographical conditions which would produce a lake or estuary of fresh or brackish water of so prodigious extent. It would appear that a subsidence which would allow the formation of a continuous body of water of that extent would let in the sea somewhat freely. In that case marine fossils would naturally be expected to bear witness to the fact, but almost no marine fossils have been found. It is, on the other hand, easy to picture the occurrence of a number of estuaries, lakes, and marshes, along the Atlantic border, occupying hollows formed by folding or faulting of the older rocks. In such isolated bodies of fresh or brackish water, we might expect precisely such deposits to accumulate as are found actually to occur. A second objection to the hypothesis of a continuous deposit is found in the frequent occurrence of coarse conglomerates along the margins of the Triassic areas. Coarse conglomerates are rarely deposited except in the immediate vicinity of a shore line. In general, if we examine the deposits now in process of formation, by a line

* For summaries of opinion on this question, see Russell, *The Newark System*, ch. IX; Hobbs, *The Newark System of Pomperaug Valley*, p. 28; Hobbs, *Former Extent of the Newark System*, in *Bull. Geological Society of America*, vol. XIII, p. 139.

† The former continuity of the Dan River and Deep River beds in North Carolina was asserted by Kerr in 1875. See *Rep. Geological Survey of North Carolina*, vol. I, p. 141.

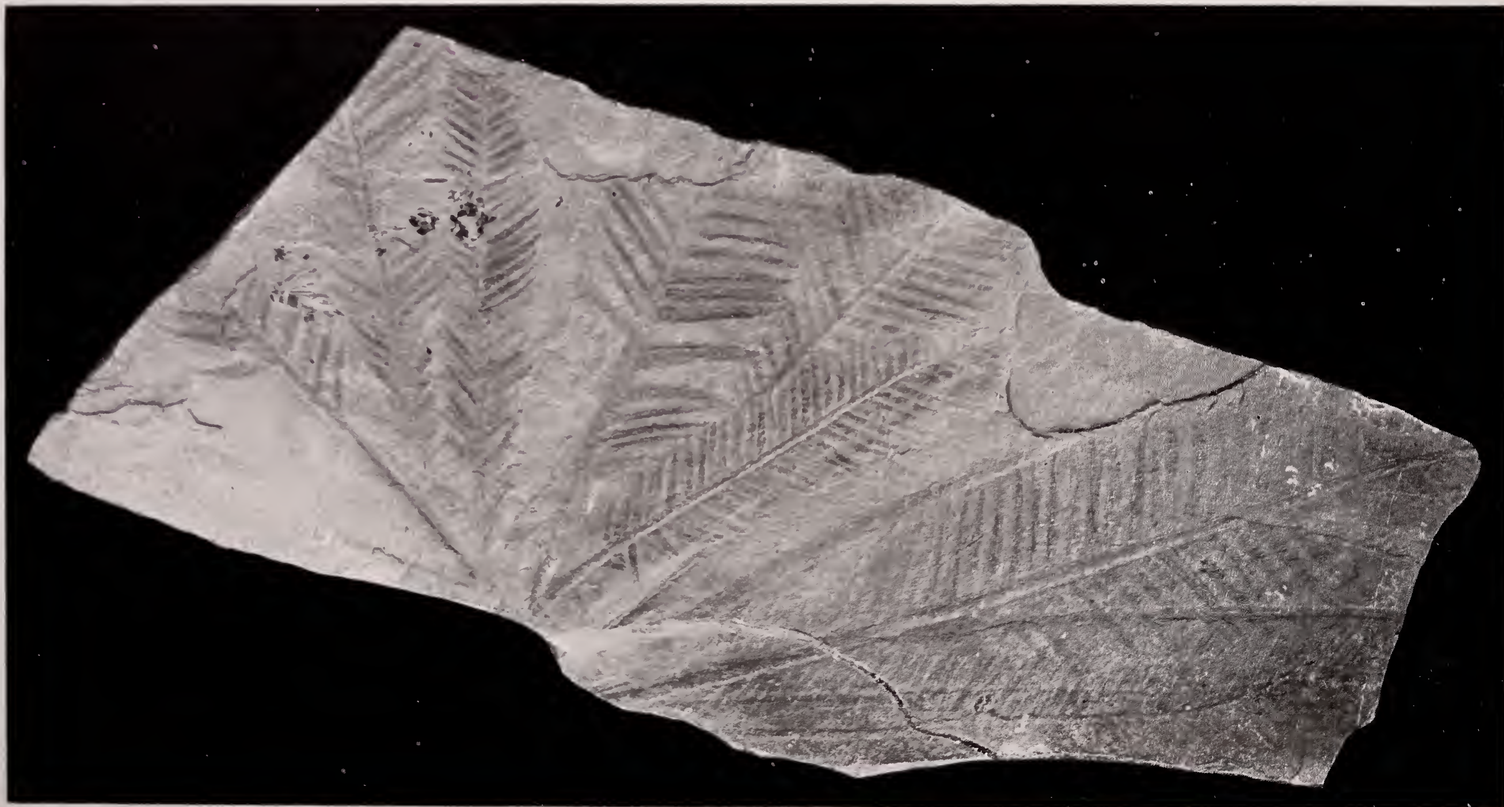
of soundings or dredgings extending from the shore line out into water of moderate depth, we shall find a gradual change from shingle and gravel through sand to fine mud. In the case of rocks of the Connecticut Valley, Percival, Emerson, and others have emphasized the fact of the occurrence of coarse conglomerates along the margins of the area, while fine sandstones and shales are found near the middle.* This would seem to indicate that the shore lines could not have been many miles from the present margins of the deposits. It is probable that, when any particular stratum was deposited, it was a coarse gravel at the edges of the estuary, but a fine sand or mud in the middle. The strong tidal currents which would have been likely to prevail in such estuaries would help to explain the movement of the very large bowlders in some of the fragmental conglomerates. It seems, therefore, on the whole, probable that the deposits in question were originally formed in isolated basins, whose extent was not very much greater than the areas now occupied by the rocks. In Connecticut, for instance, we may reasonably believe that the little area of the Pomperaug Valley was once continuous with the larger area of the Connecticut Valley; but it is not probable that the Connecticut area was ever connected with the New York-Virginia area.

FOSSILS.

Plants.— The strata of black shale which have been mentioned contain somewhat abundant remains of plants. This is especially true of the Richmond area, and of some of the other southern areas, where the conditions during part of the period of the deposition of the rocks were those of a marsh, and where the accumulation of vegetable material has resulted in the formation of beds of coal. With the exception of a few obscure and doubtful forms, the plants belong to four different groups. The Pteridophytes or Acrogens, the highest class of the flowerless plants, are repre-

* While I believe these writers are justified in asserting such a distinction between the marginal and the central parts of the formation, there are exceptions Gregory (*Farmington Folio*) has called attention to the occurrence of pretty coarse conglomerates north of Meriden and at Windsor, near the middle of the basin.

PLATE XVI.



OTOZAMITES LATOIR, DURHAM.

One-half natural size. Original in Museum of Wesleyan University. Photograph by W. M. Esten.

sented by the two groups of Ferns and Equiseta. The Gymnosperms, the lower of the two classes of the flowering plants, are represented by Cycads* and Conifers. Among the Equiseta it is noteworthy that the Carboniferous genus Calamites still survived. The general facies of the vegetation, however, is strikingly different from that of the Carboniferous, in the vastly greater development of Cycads and Conifers. The Gymnosperms were becoming the dominant group. On the other hand, the vegetation whose remains are preserved in these strata differs strikingly from the vegetation of the present time, in the complete absence of the higher class of flowering plants, the Angiosperms, which now dominate the field and forest.

Invertebrates.— The rocks have thus far afforded no Corals nor Echinoderms nor Brachiopods. The absence of these marine groups is correlated with the probable deposition of the strata in water which was fresh or at least brackish. A few species of molluscan shells have been found, some of which are believed to be fresh-water forms, more or less closely allied to the Unionidæ, or fresh-water mussels, of our present ponds and rivers. In Pennsylvania, indeed, it is believed that two species of the modern genus Unio have been recognized. The only Mollusk which has been found in the Connecticut Valley area was found in Wilbraham, Massachusetts, and has been referred to the genus Anoplophora, which is believed to represent an ancestral form from which the modern fresh-water mussels were derived.† A few shells from Pennsylvania are believed to have been marine. That occasional stragglers of marine forms should be present in an estuarine deposit is, on general principles, what might reasonably be expected. In the black shales of the New York-Virginia area and of some of the more southern areas have been found a few small Crustacea representing the two groups of the Ostracoids and the Branchiopods. In the Connecticut Valley area, both in Mas-

* A beautiful specimen showing the characteristic foliage of a Cycad is represented in Plate XVI.

† *Am. Journal of Science*, series 4, vol. X, p. 58.

sachusetts and in Connecticut, specimens have been found of the aquatic larva of a neuropterous insect. It has been described under the name of *Mormolucoides articulatus.* Some of the finer shales are marked with delicate impressions, which with much probability have been supposed to be tracks of Crustacea and Insects.

Fishes.— A number of species of Fishes have been found in the black shales, both in the Connecticut Valley area and farther south. All these fishes are included among the Ganoids.* Most of the fishes are Palæoniscoids† or Lepidosteoids. The Palæoniscoids are now entirely extinct, though the sturgeons represent an aberrant group somewhat closely related to them. The Lepidosteoids are represented by the gar-pike, or bony gar, of our western rivers. One genus of these fossil fishes belongs to the older and more primitive group of the Crossopterygians, a group which is represented among living fishes by a few species of Polypterus and Calamoichthys in the rivers of Africa. It is probable that the fossil fishes, like their nearest living representatives, were fresh-water forms.

Amphibians and Reptiles.— A number of finds of reptilian bones have been reported from the Connecticut Valley area and from Pennsylvania and North Carolina. Most of these are too fragmentary to admit of very satisfactory determination; yet these remains have sufficed to prove that the Amphibia are represented by remains of Stegocephala, and the Reptiles by remains of Crocodilians and Dinosaurs. Almost half a century ago Emmons described a pretty well preserved skull of a Crocodilian, *Rhytidodon* (*Rutiodon*) *carolinensis*, from the Deep River coal beds of North Carolina. In comparatively recent years a few discoveries of great importance have been made in the Connecticut Valley area. In 1884, near Manchester, Connecticut, was found

* This name is here used merely as a matter of convenience. The name Ganoid though widely current in the literature of the subject, does not represent a natural group.

† Catopterus is placed in this group by Zittel (in his *Grundzüge der Palaeontologie*), A. S. Woodward, and Eastman, though it shows close gradation toward the Lepidosteoids. A specimen of this genus from Durham is shown in Plate XVII.

PLATE XVII.

CATOPTERUS REDFIELDI, DURHAM.

Nine-tenths natural size. Original in Museum of Wesleyan University. Photograph by W. M. Esten.

Fig. 3. Restoration of *Anchisaurus colurus.* One-fourteenth natural size. From *Sixteenth Annual Report of U. S. Geological Survey.*

a considerable part of the skeleton of a Dinosaur, which has been named by Marsh *Ammosaurus major*. A few years later there was found in the same locality a nearly complete skeleton of another species of the same group which has been described under the name *Anchisaurus colurus*.* This specimen was so perfect as to afford Marsh satisfactory data for a restoration of the animal (Fig. 3). The animal must have been four or five feet in length. Remains of another species of the same genus have been found in the same vicinity. *Ammosaurus major* must have been an animal considerably larger than either of the species of Anchisaurus. To the genus Ammosaurus Marsh refers also the fragmentary remains found in 1865, at Springfield, Massachusetts, and described in Hitchcock's "Supplement to the Ichnology of New England," under the name *Megadactylus polyzelus*. All these forms belong to the suborder of Dinosaurs known as Theropoda. They were completely bipedal in their locomotion and were carnivorous. In 1896 was found in New Haven a considerable fragment of the dermal armor of a Crocodilian. It was described by Marsh under the name *Stegomus arcuatus*.† The entire animal may have been eight or ten feet long. Still more recently (1904) Professor Emerson has reported the discovery, at East Longmeadow, Massachusetts, of a nearly complete specimen belonging to an allied but much smaller species, *Stegomus longipes*.‡ The specimen is about six inches in length, measured to the base of the tail, most of which is missing. The Crocodilians which have been found in these rocks all belong to a suborder now entirely extinct.

While remains of reptilian bones have been comparatively rare, many layers of the deposits are crowded with tracks, which must have been made by Reptiles or Amphibians. The most abundant tracks are three-toed, and were apparently made by creatures whose locomotion was completely bipedal. In all probability these three-toed

* *Am. Journal of Science*. Series 3, vol XLII, p. 267; *Dinosaurs of North America*, in *Sixteenth Ann. Rep. U. S. Geological Survey*, part I, p. 147.

† *Am. Journal of Science*, series 4, vol. II, p. 59.

‡ *Am. Journal of Science*, series 4, vol. XVII, p. 377.

tracks are to be referred to the reptilian order of Dinosaurs. From the skeletons of Dinosaurs which have been found in considerable numbers in various parts of the world, we know that most of the members of the order must have been completely bipedal, and that the number of toes was often reduced to three, while in other species the number of toes was four, but the inner toe, the homologue of our great toe, was so small or inserted so far above the level of the others as to make no impression in the track. Such a Dinosaur, then, would make a single row of three-toed tracks, which is exactly the character of the most abundant tracks in our Triassic formation. Fig. 4 represents perhaps the most common species of tracks of this type. It is believed by Dr. Lull to be the track of *Anchisaurus colurus*.* The bones of the foot, represented in the figure in connection with the outline of the track, are those of *Anchisaurus colurus*. In other cases, associated with the large tracks supposed to have been made by the hind feet, are occasional smaller tracks, indicating that, while the creatures were mainly bipedal in their locomotion, they occasionally placed their fore paws on the ground. This was the case with *Otozoum moodii*, which was apparently the largest of all the animals whose tracks are found in the Connecticut sandstones. The tracks of its

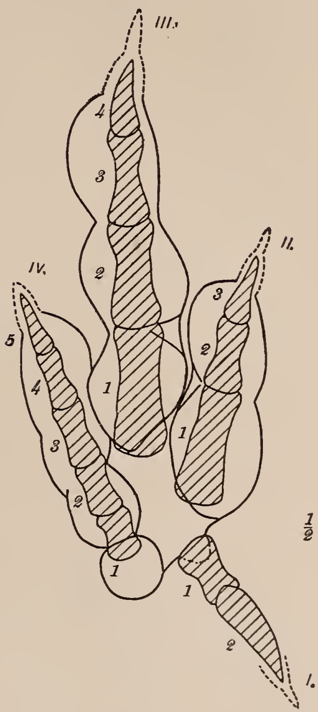


FIG 4. Track of *Anchisauripus dananus* (*Brontozoum sillimanium*). One-half natural size. The bones represented in the diagram are those of *Anchisaurus colurus*. From Lull, *Fossil Footprints of the Jura-Trias*.

* *Memoirs of Boston Society of Natural History*, vol. V, p. 487.

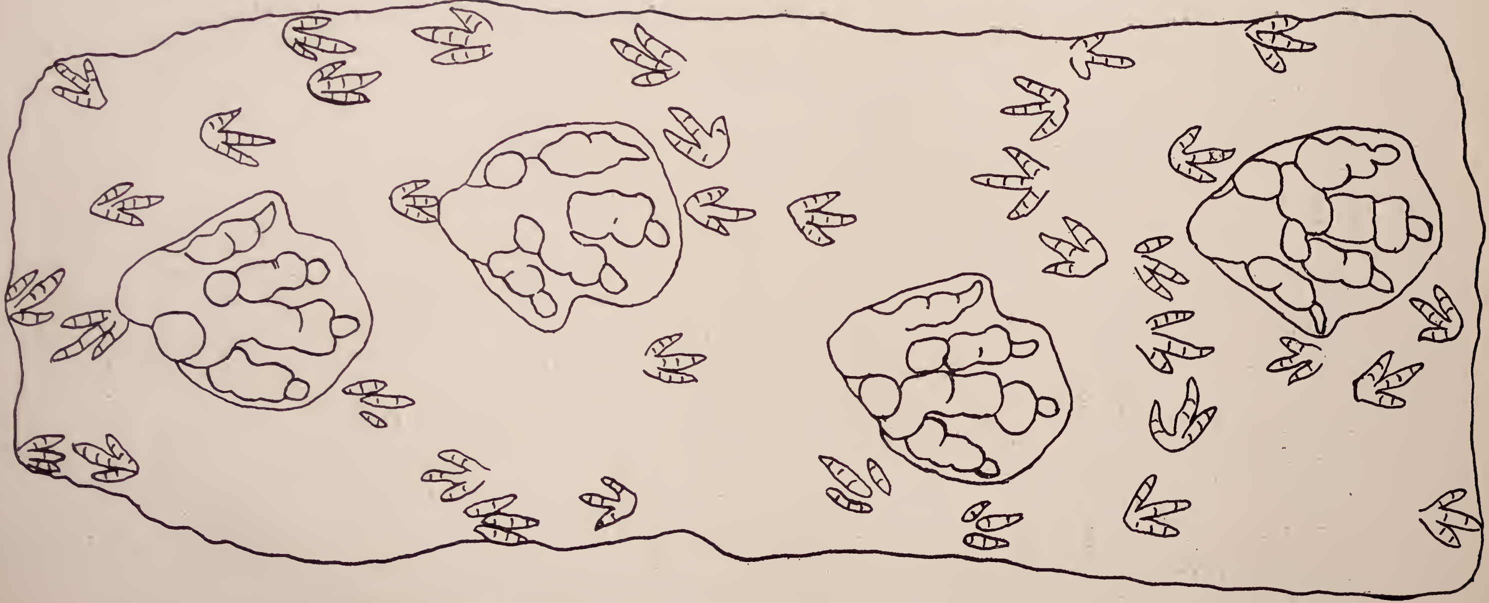


Fig. 5. Tracks of *Otozoum moodii* and *Anchisauripus dananus*. One-sixteenth natural size. From Hitchcock, *Ichnology of Massachusetts.*

hind feet are about twenty inches in length. Fig. 5 represents a series of these huge tracks, associated with several tracks of the more abundant *Anchisauripus dananus* (*Brontozoum Sillimanium*). While all the dinosaurian bones and teeth which have been discovered belong to the carnivorous suborder Theropoda, some of the tracks indicate animals whose toes were armed with blunt claws such as would seem unsuitable for a carnivorous animal. Dr. Lull has raised the question whether some of these tracks may not have been made by representatives of the Predentata — herbivorous, mostly bipedal, Dinosaurs.* No skeletons of Predentata have been found in any part of the world in any formation as early as the probable date of the Connecticut sandstone. Still other tracks — for the most part small ones — were made by creatures that were unquestionably quadrupedal, the separate impressions of the fore and hind feet being clearly distinguishable. One type of these small quadrupedal tracks, represented in Fig. 6, was probably made by little Crocodilians, like the one whose skeleton has recently been brought to light from Massachusetts.† A few of the tracks have been very doubtfully attributed to Turtles. Of course there is a considerable element of conjecture in the identification of animals on the evidence of tracks alone; and, while most of these tracks were doubtless made by Reptiles, it is not unlikely that some of them were made by Amphibians.

½

FIG. 6. Tracks of *Batrachopus* (*Anisopus*, *Anisichnus*) *gracilis*. One-half natural size. From Lull, *Fossil Footprints of the Jura-Trias*.

* *Op. cit.*, pp. 499, 544.

† Lull, *Am. Journal of Science*, series 4, vol. XVII, p. 381.

Birds.— The three-toed tracks which have just been mentioned are often popularly spoken of as bird-tracks; and that is not unnatural, for a three-toed bipedal track is very suggestive of a bird. It is, however, highly improbable that the class of Birds was in existence at the time of these deposits. No skeletons of birds have been found in any part of the world in any formations earlier than the upper part of the Jurassic. The formation in question must pretty certainly be referred to a considerably earlier date. It is, however, known, by the clear evidence afforded by skeletons, that, at the time when we must suppose these strata to have been deposited, Dinosaurs, which would make substantially bird-like tracks, must have been abundant. The gigantic size of some of the three-toed tracks is to some extent confirmatory of their reference to Dinosaurs rather than birds. The birds of the Jurassic era, and most of those of the Cretaceous, were comparatively small animals. Very large birds, like the modern ostriches, are not known to occur until a considerably later period. But many of the Dinosaurs in all Mesozoic time were gigantic.

Mammals.— No remains of Mammals have been found in the rocks of the Connecticut Valley. In North Carolina, however, have been found two little jaws, which are supposed to represent two different species and even two different genera of Mammals. These little jaws show a very peculiar type of molar teeth. In general, mammalian molars have the root divided into two or more fangs, while the simpler teeth of Reptiles show a single undivided root. In the teeth of these little fossils, the root is grooved, indicating a transition from the simpler form of the reptilian tooth to the completely divided fangs of the mammalian tooth. There has been, indeed, some doubt among paleontologists as to whether these little relics are truly mammalian or reptilian. In all probability they represent an extremely primitive type of Mammal, in which the characters of the more typical Mammals had not yet been completely evolved. It is a reasonable conjecture that, if we could study the complete anatomy of these little creatures, we might find some

of those same peculiarities of the skeleton and of the soft parts, particularly of the reproductive organs, which now characterize the duck-bill and the spiny ant-eater of Australia, the lowest and most reptilian of living Mammals. These modern Monotremes are toothless, at least in their adult condition; but it is altogether probable that the most primitive Monotremes, like the Reptiles, from which they must have been derived, possessed teeth.

THE AGE OF THE ROCKS.

The formation which we are considering has been thus far called provisionally Triassic. This seems the proper place for a word in regard to the evidence upon which the rocks are referred to that era. The fundamental criterion by which the relative age of stratified rocks is determined is the order of superposition of the strata. It is self-evident that every stratum is newer than the strata upon which it has been deposited, and older than any strata which have been deposited upon it; and upon this simple principle rests the whole scheme of the history of successive geological periods.

It is, however, obvious that the criterion of superposition can be employed only within the limits of particular districts of country. We cannot prove that a stratum in Connecticut underlies or overlies a stratum in England or in North Carolina. The only available means for determining the comparative age of rocks of different districts of country is found in the fossils which they contain. When the order of succession of strata has been made out independently in a number of districts of country, and the characteristic fossils of each stratum have been catalogued, there has been brought to light the profoundly significant fact that the order of succession in fossils is substantially the same all over the world. The series of fossiliferous formations is not indeed complete in any one district, but the order of those members of the series which are present in any particular district is never inverted. If, for instance, in one locality, as in England, an assemblage of fossils which we may call

A, B, C, is observed in one stratum, and in an overlying stratum is found an assemblage of fossils which we may call *D, E, F,* then nowhere in the world will the assemblage of fossils *D, E, F* be found underlying the assemblage *A, B, C.* The law which has been stated is an induction from a vast series of observations, and is abundantly verified as a general law, even though there may be isolated exceptions as regards the position of particular genera or species.

While this law has been developed inductively by the study of fossils, it may be recognized as probable *a priori* on the basis of the theory of evolution. It is a reasonable supposition that the broad outlines of the evolutionary history of plants and animals are due to causes operating simultaneously in all parts of the world. It is therefore probable that the broad outlines of evolutionary history have been the same in different continents or in different oceans. It is also reasonable to suppose that the vicissitudes of geological time have permitted or compelled migration in all sorts of directions, and by such migration the tendencies to divergent evolution in different parts of the earth's surface must have been largely held in check. It is, however, obvious that different groups of organisms must be of unequal value as criteria of geological age. Conditions of life in shallow seas adjoining the continents differ much less than conditions of life in different land areas. Hence there is much less tendency to faunal divergence in the case of marine organisms than in the case of terrestrial organisms. In the distribution of organisms at the present time, it may be observed that marine species are apt to have wider ranges than terrestrial, and that the difference between the faunas of different seas is much less than between the faunas of different continental areas. The same must have been true, in greater or less degree, in former geological times. It is also true, in general, that the higher and more complex organisms depend upon a more exquisite adaptation to particular conditions of existence than do the lower organisms. The differences between the mammalian faunas or different continents today are much more strongly

marked then the differences between the invertebrate faunas of different areas. For both of these reasons, therefore, the marine invertebrates are by far the most serviceable fossils in the discrimination of the age of deposits. The value of some groups of marine invertebrates as criteria of geological age is further enhanced by the fact that, owing to the conditions in which they live, and the large quantity of mineral matter in their tissues, they are preserved in fossil condition in immense numbers. Mollusks and brachiopods, crinoids and corals, are in general the most abundant fossils. It may be considered certain that our knowledge of the molluscan life of different periods is vastly less incomplete than our knowledge of avian or mammalian life.

Applying these principles to the formation which we are considering, we must say, in the first place, that the direct stratigraphic evidence in the case of the sandstones of the Connecticut Valley area gives us very little information. The Connecticut Valley sandstones rest unconformably upon the crystalline schists of the Highland areas. It is remarkable that in Connecticut actual contact has been observed only in a single locality — the ravine of Roaring Brook, in Southington.* The clearly marked unconformability of this contact shows that the sandstones were formed, not only subsequently to the original deposition of the schists, but subsequently to their tilting and metamorphism and to a considerable amount of erosion. But the destruction of fossils in the metamorphism of these crystalline rocks has left us destitute of any definite knowledge of their age. All that we can be sure of in regard to the crystalline rocks is that they are not later than the Paleozoic. The stratigraphy of the Connecticut Valley area affords no other indication of an upper limit of the age of the sandstones than the fact that they are overlain by Glacial drift. In some of the other areas, however, more definite information is afforded by the stratigraphy; and there is no reasonable doubt that the deposits in all the areas which have been enumerated† are substantially identical in age. In Nova

* See page 81, and Plate XIII

† Page 162.

Scotia, the formation in question overlies unconformably Carboniferous strata. In New Jersey, the formation is overlain by the Potomac formation, which has been generally considered to be Lower Cretaceous, though it is possible that the lowest beds of the Potomac may belong to the uppermost part of the Jurassic. Stratigraphical evidence, then, leads to the conclusion that the red sandstones and associated rocks are not older than the Triassic and not later than the Jurassic.

We have already seen that, with the exception of a very few molluscan shells, no marine invertebrates are found in any of the areas of this formation. We are then practically destitute of those fossils which are of the greatest value in the determination of the age of the strata. Some of the strata of the European Triassic and Jurassic abound in marine fossils, but there are no means of correlating the sandstones in question with those marine strata. The best paleontological evidence which is available is afforded by comparison of the fossil plants, which occur abundantly in some areas of the formation, particularly in the Richmond area, with the fossil plants of some of the European strata. Such a comparison shows that the flora of these sandstones finds its nearest equivalent in that of the Keuper, the uppermost division of the European Trias. The indications afforded by the fishes and reptiles, though more scanty, are in harmony, so far as they go, with the evidence of the plants. It is therefore altogether probable that we are justified in applying to the Connecticut sandstones and the corresponding formations of other areas the name of Triassic. In the somewhat unsatisfactory condition of the evidence in regard to the age of these formations, some geologists have been accustomed to speak of them under the name Jura-Trias, thus avoiding a more definite expression of opinion in regard to the age. In the publications of the United States Geological Survey, the formation has been generally called the Newark formation, the name being derived from the city in New Jersey. It seems, however, best to apply to the rocks in question the name Triassic, though

it must be conceded that the evidence is not such as to exclude all doubt.

THE TRAP ROCKS.

Associated with the sandstones and other stratified rocks are extensive terranes of igneous rock, whose history and whose relations to the stratified rocks present many interesting problems. These igneous rocks are commonly known under the name of trap, the name trap denoting vaguely a dark, basic, rather fine-grained igneous rock, without regard to its definite chemical or mineralogical constitution.

Mineral Constitution.— With insignificant exceptions, to which reference will be made later, the igneous rocks of these Triassic areas present a remarkable degree of uniformity of character. They consist chiefly of augite and labradorite. While labradorite is the predominant feldspar, there is often present some other species of triclinic feldspar, which is andesine or anorthite, at least in most cases. Chrysolite (olivine) and apatite occur sparingly in the rock, and the former is sometimes altered to serpentine. Magnetite, the magnetic oxide of iron, occurs often in such abundance that the rock masses show themselves strongly magnetic. If a compass is moved about on the surface of one of our trap hills, the needle will often change its direction ninety degrees or more when moved only a few inches. The chemical work done in the laboratory of the New Jersey Geological Survey has shown that the trap rocks of that area sometimes contain not only magnetite, but metallic iron in minute grains.* The same is very probably true of the trap of other areas. Chlorite appears often as an alteration product in traps that are somewhat decomposed. The rock is generally fine-grained, but is almost always holocrystalline, or nearly so. Its solidification was too rapid to permit the coarse crystallization which characterizes the plutonic rocks, but not sufficiently rapid to form any considerable amount

* *Ann. Rep. State Geologist*, 1874, p. 56.

of glass. A rock such as is described above would be called a diabase or basalt. Typically, diabase is holocrystalline, while basalt contains at least traces of glass. Diabase shows in general a coarser crystalline grain than basalt. We shall see later (page 192) that some of the Connecticut traps are lava sheets, while others solidified below the surface in fissures in the sandstones. On the average, the extrusive traps are somewhat finer-grained than the intrusive, and the former are more likely to show a little glass when examined under the microscope; though specimens could doubtless be selected from the extrusive traps (especially from near the middle of the main sheet) which could not be distinguished from other specimens that might be selected from the intrusive traps. In recent publications, the United States Geological Survey has called the extrusive sheets basalt, and the intrusive dikes and sheets diabase. That usage will accordingly be followed in the present work and in other Bulletins of the Connecticut State Survey.

The following analysis (by Dr. J. H. Pratt) of the basalt of the main sheet, from Meriden, is taken from Professor Gregory's paper in the Farmington Folio of the United States Geologic Atlas: —

SiO_2	52.37
Al_2O_3	15.06
Fe_2O_3	2.34
FeO	9.82
TiO_2	.21
MnO	.32
MgO	5.38
CaO	7.33
K_2O	.92
Na_2O	4.04
H_2O	2.24
	100.03

In many localities the basalt of the extrusive sheets was rendered vesicular by the expansion of steam in the molten

PLATE XVIII.

TRAP COLUMNS, RABBIT ROCK, NORTH HAVEN.

Photograph by H. H. Robinson.

mass. The vesicles vary from microscopic dimensions to a diameter of several inches or even feet. The vesicles are generally filled or lined by minerals, often beautifully crystallized, which have been chemically deposited by percolating water. The rock is then said to be amygdaloidal. In the Connecticut Valley area, the minerals most frequently occurring in the cavities of amygdaloid are quartz, calcite, chlorite, prehnite, and datolite. The quartz is sometimes in drusy crystallizations, but sometimes it has the form of chalcedony or agate. Occasionally sulphuric acid, formed by oxidation of pyrite, has converted the calcite into gypsum or anhydrite. Zeolites appear to be rare in Connecticut, though occurring in great abundance in the amygdaloids of Nova Scotia and New Jersey. Asphaltum is occasionally found in the cavities of our amygdaloids.

Columnar Structure.— In the cooling of igneous rocks, it is often the case that cracks are developed, dividing the rocks into prismatic forms. This structure is commonly called the columnar structure, and is exhibited in great perfection in many localities of igneous rock. Theoretically, these shrinkage cracks, if the rock were perfectly homogeneous, and cooling advanced at an equal rate in all parts, should meet at angles of 120°, and divide the mass into hexagonal prisms. In spite of much irregularity, a tendency to hexagonal forms is often obvious. The direction of the axis of the columns should be perpendicular to the cooling surface. The trap rocks of the Connecticut Valley often exhibit the columnar structure in a rude and irregular manner. In a few places pretty regular columns are observed. The best example which has been noted in the state of Connecticut is at Rabbit Rock, near New Haven (see Plate XVIII). The Massachusetts geologists have called attention to good examples of columnar structure at Mt. Holyoke. Still finer examples of columnar structure in trap are to be seen in the vicinity of Orange, New Jersey.

Modes of Occurrence of the Trap.— The trap sometimes occurs in dikes, cutting across the strata at a high angle.

In the Connecticut Valley area, dikes seem to be especially abundant in the southern part of the area. Numerous small dikes and some large ones are observed in the vicinity of New Haven. The hills called Pine Rock and Mill Rock are formed by large dikes. The trap of Mt. Carmel appears to be a complex mass of dikes.

The larger masses of trap in the Acadian, the Connecticut Valley, and the New York-Virginia areas have the character of sheets; that is, instead of cutting across the strata at a high angle, they extend nearly or quite parallel with the associated strata, so that they seem to have the stratigraphical relations of truly stratified rocks. In Connecticut, we find two lines of outcrop of trap close to the western margin of the area, one of them extending from New Haven to Cheshire, and the other extending, with some interruption, from Avon to Granby (see Fig. 1, page 19). Whether these were ever continuous with each other is unknown. Farther east there may be traced, with many interruptions, the cause of which will be explained hereafter, the approximately parallel outcrops of three sheets of trap, extending across the state from East Haven to Suffield, not far from the middle of the Triassic area. The westernmost of the three was called by Percival the anterior sheet, and the easternmost the posterior sheet. The middle one is much thicker than either of the others, and is commonly spoken of as the main sheet. Davis estimates the thickness of the anterior sheet as about 250 feet, that of the main sheet 400 to 500 feet, and that of the posterior sheet 150 or 200 feet. The names anterior and posterior were given by Percival in a purely descriptive sense. The massive main sheet, being much more resistant to erosion than any other rocks in the Connecticut Valley, has been a controlling influence in the topography of the valley. Its outcrop is marked by a series of picturesque ridges, all having a gentle slope on the east side and a steep slope on the west side. This form results from the fact that the sandstones and the associated trap sheets have a gentle dip to the east. The topographical

effect of the action of erosion upon a gently dipping monocline composed of strata of unequal hardness, is always to develop unsymmetrical ridges, having a gentle slope following the dip, and a steep slope on the other side of the ridge.* It is not unnatural to call the steep side the face of the ridge, and the gentle slope its back. The westernmost of the trap sheets, cropping out under the steep face of the ridges formed by the main sheet, was accordingly called by Percival the anterior; and the eastern sheet, whose outcrops lie just to the east of the back slopes of the ridges formed by the main sheet, was called the posterior. It will appear hereafter that the names anterior and posterior have now acquired also a chronological significance, the westernmost of the three sheets being the earliest in date. Of these three sheets which extend through the middle of the Connecticut Valley, the anterior is confined to the state of Connecticut, but the main sheet and the posterior sheet extend into Massachusetts, at least as far as Mt. Holyoke. Whether the trap sheet which appears in the vicinity of Deerfield, Massachusetts, was originally a part of the main sheet of the southern Connecticut Valley, or an independent local eruption, is not certainly known.

Contemporaneous and Intrusive Sheets.— When a mass of igneous rock lies between two strata, with its bounding surfaces parallel or nearly parallel to the planes of stratification, it is obvious that there are two possible ways in which such a collocation of the rocks may be explained. It may be that, after the deposit of both the underlying and the overlying strata, the rocks were split apart by some strain, and molten rock flowed into the crack. Such a sheet is essentially of the same nature as a dike, each of these structures resulting from the intrusion of a molten rock into a crack in preexistent rocks. The only difference is that in one case the crack cuts across the planes of stratification, while in the other case the crack is parallel to the planes of stratification. Since planes

* See Fig. 10, page 205.

of stratification must always be planes of weakness in a rock, it is obvious that we may expect such sheets to be of frequent occurrence. Such a sheet is called an intrusive sheet. The other possible interpretation of a mass of igneous rock apparently interstratified with a series of sedimentary deposits, is that the igneous rock flowed out as a lava sheet, either upon the surface of the ground, or at the bottom of a body of water, after the deposition of the underlying strata, and before the deposition of the overlying strata. After a lava sheet had cooled and solidified, if it was originally under water, or if by subsidence it was carried below the water level, a subsequent series of strata might be deposited upon it. A sheet of igneous rock which flowed out thus upon the surface and was subsequently covered by sedimentary deposits of later date, is called a contemporaneous or extrusive sheet.

Criteria for the Discrimination of Contemporaneous and Intrusive Sheets.— It is obvious that in general a contemporaneous sheet, being exposed on its upper surface to the atmosphere or to a body of water, will cool more rapidly than an intrusive sheet of equal thickness, since the latter can lose heat only by the comparatively slow process of conduction through the rocks. An intrusive sheet, therefore, is apt to show a coarser crystalline grain than a contemporaneous sheet. A contemporaneous sheet may, in fact, cool so rapidly as to be glassy in parts. It is, however, obvious that the coarseness of crystallization must depend very much upon the thickness of the sheet and upon many local conditions. A thick contemporaneous sheet might cool more slowly than a thin intrusive sheet.

Since a contemporaneous sheet solidifies under little more than atmospheric pressure, it is apt to be rendered vesicular by the expansion of the steam which is contained in it. Subsequently the vesicles may be filled by the deposit of crystalline material from percolating waters, producing an amygdaloidal structure. If a contemporaneous sheet is of considerable thickness, the deeper portions of it will solidify under a pressure very much greater than that at the surface;

PLATE XIX.

TRAP CLIFF, AND BUILDINGS OF TRINITY COLLEGE, HARTFORD.

The contact of the trap with the underlying strata is of the type characteristic of extrusive sheets.
Photograph taken under direction of W. M. Davis for U. S. Geological Survey,

PLATE XX.

TRAP RESTING ON OBLIQUELY TRUNCATED EDGES OF STRATA, WEST ROCK, NEW HAVEN.

Type of contact characteristic of intrusive sheets.
Photograph taken under direction of W. M. Davis for U. S. Geological Survey.

hence it is very commonly the case in contemporaneous sheets that the superficial portions are highly amygdaloidal while the deeper portions are much more compact. As a lava sheet spreads itself over the surface of the country, the more rapid motion of the superficial portions as compared with the deeper portions sometimes results in the under-rolling of a portion of the vesicular crust which has been already formed upon the surface. In this way it sometimes comes to pass that a contemporaneous sheet is amygdaloidal both at the top and at the bottom, while it is compact in the interior. Since all parts of an intrusive sheet solidify under a considerable pressure, the rock is generally not vesicular at all. In the exceptional cases in which portions of an intrusive sheet are amygdaloidal, the amygdaloidal character is not systematically limited to the upper and lower surfaces.

The surface of contact between a contemporaneous sheet and the underlying strata will usually be exactly accordant with the planes of stratification. There may be, of course, exceptions, in cases in which the surface of the strata had been exposed to erosion for some length of time before the outflow of the lava. In an intrusive sheet, on the other hand, it will seldom be the case that the surface of contact, either with the underlying or with the overlying strata, will be for long distances exactly accordant with the planes of stratification. In the great majority of cases, though the fracture may, in a general way, follow the planes of stratification, it will here and there break across the strata, following for short distances joint planes or irregular surfaces of feeble cohesion due to local variation in the texture of the rock. This distinction may be very strikingly illustrated by a comparison of the contact of the trap and the underlying sandstones in the bluff at Trinity College, in Hartford, with that at West Rock, New Haven, as shown in Plates XIX, XX. In the former case, the contact, which is exposed for a long distance in the face of the bluff, is perfectly accordant with the stratification, while in the latter the contact cuts obliquely across a considerable series of layers.

Stratified rocks are apt to undergo a greater or less amount of metamorphism in contact with molten rock. The change may be simply induration. Oftentimes there is a change of color. The shales of the Connecticut Valley often assume a peculiar purple color near the contact with the trap. Sometimes a highly crystalline texture is developed in the sandstones. If the molten rock comes in contact with a mud still imperfectly consolidated, the expansion of the water into steam may give a vesicular character to the stratified rock, and the vesicles may come to be filled with crystalline minerals like the vesicles of an amygdaloid. It is obvious that an intrusive sheet will produce metamorphic changes upon both the underlying and overlying strata, while a contemporaneous sheet can metamorphose only the underlying strata.

If a contemporaneous sheet is poured out at the bottom of a body of water, the superficial crust of igneous rock may become cracked and broken into fragments, and those fragments may be rolled about by currents in the water. They may thus come to be mingled with the mud or sand or gravel derived from other sources which the waters are transporting and depositing. It is accordingly often the case that a contemporaneous sheet is immediately overlain by a conglomerate consisting largely of fragments of the igneous rock itself. It would be, of course, impossible for a similar condition to be developed at the top of an intrusive sheet. The molten rock of an intrusive sheet, on the other hand, may often flow up into cracks in the overlying strata, thus forming little dikes. A very striking example of this is to be seen in the ravine of Roaring Brook in Cheshire. The criteria mentioned in this paragraph are in general more perfectly unmistakable than most of the others. The coarseness of grain of the igneous rocks, the amount of vesicularity, the degree of induration or apparent alteration in the sedimentary rocks, may vary greatly as the result of a variety of causes. But a conglomerate overlying a sheet of igneous rock and containing fragments of that rock affords indubitable evidence that the

PLATE XXI.

SURFACE OF LOWER LAVA FLOW, MAIN TRAP SHEET, MERIDEN.

Upper Lava Flow is seen in background.
Photograph by J. R. Harris.

sheet is contemporaneous; and dikes proceeding from a sheet of igneous rock into the overlying strata afford equally indubitable evidence that the sheet is intrusive.

A contemporaneous sheet may often be double or multiple. A certain amount of lava may flow out, and subsequently a second outflow may take place over the already consolidated surface of the former. In the great trap quarry at the southeastern corner of the Hanging Hills in Meriden, it is clearly seen that the main sheet is double. The compact trap of the upper flow can be seen resting upon the hummocky surface of the highly amygdaloidal trap, which forms the top of the lower flow, as shown in Plate XXI. A band of decomposing amygdaloidal trap, underlain and overlain by compact trap, reveals in like manner the fact of a double flow in the posterior sheet near Westfield, just north of the Sebethe River. It is obvious that such a multiple structure would be impossible in an intrusive sheet.

Since outflows of lava are often associated with explosive eruptions, it follows that a contemporaneous sheet may be locally associated with or replaced by tufaceous deposits. In southern Connecticut, the anterior trap sheet in the parts corresponding to Salstonstall Mountain and Totoket Mountain is associated with very extensive tufaceous deposits. In the vicinity of Mount Holyoke in Massachusetts, the trap of the posterior sheet is overlain by very extensive tufaceous deposits. It is needless to say that an intrusive sheet cannot be associated with ashes or tufa or other evidences of explosive eruption.

When a contemporaneous sheet runs over the surface of soft mud at the bottom of a body of water, it may happen that the contact of the water will chill the bottom of the lava sheet, so as to form a crust, above which the lava is still liquid. The heat of the lava may then produce so much steam in the mud under the crust that it will here and there burst up through the crust, so that a mass of mud and water and fragments of the already solidified igneous rock may be carried up into the interior of the molten mass. The very peculiar structure displayed in the anterior trap sheet

west of Lamentation Mountain in the northern part of Meriden is perhaps best explained in this way, though the locality was first described as an ash bed, and is popularly known in the vicinity as "the Volcano."* It is obvious that no similar structure could be produced in connection with an intrusive sheet.

The application of these criteria has established beyond a reasonable doubt the character of the trap masses of the Connecticut Valley. The accumulation of the evidence has been the work of much labor, since, as can easily be seen from the general statement given above, the criteria for the distinction of contemporaneous and intrusive sheets are mainly to be found at the contact with the overlying strata, and, in the Connecticut Valley, these upper contacts are in most places concealed by drift and vegetation. Careful search, however, has revealed these upper contacts in a good many localities. The trap sheet near the western border of the Triassic formation in southern Connecticut, extending from West Rock, New Haven, to the north end of Gaylord's Mountain in Cheshire, is very certainly intrusive. East Rock, New Haven, is also unquestionably intrusive. The same is true beyond reasonable doubt, though the evidence is not quite so complete, in regard to the trap sheet on the western border of the formation in northern Connecticut, extending from Avon to Granby. On the other hand, there is no reasonable doubt that the three trap sheets which may be traced across the whole breadth of Connecticut, from Saltonstall Mountain in East Haven to Suffield, and two of which can be traced still farther to Mount Holyoke in Massachusetts, are contemporaneous. Upper contacts have been discovered in a number of localities on the back of each of the three sheets — the anterior, the main, and the posterior. Their amygdaloidal upper surfaces, the complete absence of any metamorphism of the overlying sandstones, and the frequent occurrence of a trap conglomerate immediately overlying the trap sheet, have left no doubt in

* Emerson, *Diabase Pitchstone and Mud Enclosures of the Triassic Trap*, in *Bull. Geological Society of America*, vol. VIII, pp. 66, 72.

the minds of most geologists who have studied the phenomena.*

The Traps of New Jersey.— The investigations of Darton and others have shown that the great sheet of the Palisades on the west bank of the Hudson is intrusive, while the trap of the Watchung Mountains farther west is contemporaneous. The complementary relation of the positions of the intrusive trap in Connecticut and in New Jersey is highly significant. As the Connecticut strata dip to the east and the New Jersey strata to the west, the lowest strata of the formation are found along the western border in Connecticut and along the eastern border in New Jersey. In each case the great intrusions of igneous rock have taken place in the lower strata of the formation.†

Age of the Intrusive Sheets.— It is obvious that the contemporaneous sheets belong to an epoch which, roughly speaking, is not far from the middle of the period in which the sandstones were deposited. They are, of course, newer than the underlying strata, older than the overlying strata. But the relation of an intrusive sheet to the stratified rocks fixes a limit for the time of intrusion only on one side. We know that the intrusive sheets must be later than the overlying strata, but how much later does not appear. While it is impossible to determine the age of the intrusive sheets as definitely as that of the contemporaneous sheets, there is a strong probability that the age of the intrusive sheets is not very different from that of the contemporaneous sheets. The fact that in Connecticut the intrusives are found only in the sandstones underlying the anterior contemporaneous sheet, is very suggestive of the conclusion that the date of these intrusives was prior to that of the deposition of the upper strata of the formation. Davis has shown that in all probability the intrusive sheets are dislocated by some of

* For details in regard to localities, the student may refer to the papers of Davis; particularly in *Eighteenth Ann. Report U. S. Geol. Survey*, vol. II, pp. 48-77, and in *Bull. Museum of Comparative Zoölogy*, vol. XVI, pp. 99-138.

† The intrusive trap of Sourland Mountain in New Jersey, though not near the eastern border of the formation, is associated with strata probably below the middle of the series, brought up to the surface by a great fault. Kümmel, in *Ann. Rep. State Geologist of New Jersey*, 1897, pl. II.

the same faults which have dislocated the contemporaneous sheets. Those faults were probably produced, at least for the most part, at the same time at which the strata were elevated and tilted and the old estuary was finally drained. This line of reasoning would show, of course, that the intrusive traps cannot be later than the time of the tilting and faulting. It is then a probable conclusion, though the evidence is not altogether conclusive, that the date of the most of the intrusions is not far from the date of the contemporaneous eruptions.

Volcanoes.— It is certain that there are no volcanoes in Connecticut at present. Whatever volcanoes may have existed, have long since been buried beneath later deposits or removed by the processes of erosion. The outpouring of vast sheets of lava may take place along great fissures without the formation, at least on any considerable scale, of volcanic cones. In recent times some of the lava eruptions of Iceland seem to have been of this type. Fissures have opened a score of miles or more in length, and the lava has poured out in vast floods without any explosive forms of eruption. The extensive tufaceous deposits, however, which are found in connection with the anterior sheet in southern Connecticut, and in connection with the posterior sheet in the region of Mount Holyoke, suggest the probability that volcanic cones of greater or less extent were formed at the time of these eruptions. It is a noteworthy fact that dikes are very abundant south of Cheshire and Wallingford, while they seem not to occur in the northern part of the formation within the state of Connecticut. It is a plausible conjecture that some of these dikes may mark the sites of old volcanoes, though the cones themselves have long since disappeared. Through some of the fissures now marked by dikes there may have come to the surface not only flows of lava, but explosive discharges of ashes, which may have accumulated locally in cones of considerable height. Davis has plausibly conjectured that the trap mass of Mt. Carmel may have been the root of a large volcano.* Emerson has

*_Eighteenth Ann. Rep. U. S. Geological Survey_, vol. II, p. 44.

shown strong evidence for the belief that in the vicinity of Mount Holyoke the closing phase of igneous activity consisted in discharges from typical volcanic cones. The plugs of lava marking the site of the volcanic chimneys may still be recognized, though the cones have been removed by erosion.*

It may be proper to remark in this connection that the topography of the trap rocks in the Connecticut Valley has no relation whatever to the form of volcanoes. As has been already remarked,† the outcrops of the main sheet, and to some extent the outcrops of the feebler anterior and posterior sheets, are marked by unsymmetrical ridges, having a gentle slope in the direction of the dip and a steep slope on the other side of the ridge. Substantially the same form is seen in the ridges which were formed by the intrusive sheets of trap. It is then entirely independent of the question whether the trap is contemporaneous or intrusive. It has, in fact, no relation to the igneous origin of the trap. It is simply an erosion form resulting from the fact that the trap is more resistant than the sandstones and shales with which it is associated. If the trap were replaced by a peculiarly hard stratum of grit or quartzite, the topographical form would be exactly the same. In fact, the form of the trap ridges in Connecticut is strikingly similar to that of some ridges in the Pennsylvania Appalachians formed by the Medina sandstone.

Peculiar Igneous Rocks.— While in general the trap rocks of the Connecticut Valley, whether contemporaneous or intrusive, show a remarkable uniformity in chemical and mineralogical constitution, a few cases have been observed of dikes of very different types of rock. In East Haven there are small dikes of a much more acidic type of rock, consisting chiefly of feldspar, and described by Hovey as a keratophyre.‡ In Middlefield, near the village of Baileyville, there is a dike of an exceedingly basic rock, consisting

* *Geology of Old Hampshire County*, pp 411, 481.
† Page 32.
‡ *Am. Journal of Science*, series 4, vol. III, p. 287.

chiefly of augite, porphyritic with large crystals of augite and hornblende.*

VEINS AND OTHER SECONDARY DEPOSITS.

The sandstones of the Connecticut Valley are traversed in various places by veins of barite, often associated with copper ores. The largest barite veins are those of Cheshire. At that locality malachite, chalcocite, bornite, and native copper occur in the barite, but in quantities too small to be of any economic significance. The veins, however, were formerly worked for the barite itself, which was mixed with white lead in the manufacture of white paint. At Edgewood (formerly Whigville), near Bristol, copper ores have been found in considerable quantity, partly in the sandstones and partly in the crystallines, near the contact of the two formations. The workings at this locality were commenced on a somewhat larger scale in 1836, though some work had been done before the close of the eighteenth century. After an interruption of many years, the work was again prosecuted between 1888 and 1895. The Bristol copper mine has been famous for the splendid crystals of chalcocite which it has yielded. Copper ores, chiefly chalcocite and malachite, occur in East Granby, disseminated through a gray sandstone. A company for the working of a mine at this locality was chartered as early as 1709. For about sixty years in the latter part of the eighteenth and the early part of the nineteenth century, the old mine was used as a prison. The working of the mine was resumed about 1830 and prosecuted for a time. Native copper has been found at a number of localities in thin plates or threads in the trap. Masses of native copper have been found occasionally in the drift, which in all probability were derived from the Triassic rocks of Connecticut or Massachusetts. Among the finds of this sort reported are a mass of ninety pounds found in Hamden in the latter part of the eighteenth century, and one of two hundred pounds found near New Haven.

---

* *Bull. Museum of Comparative Zoölogy*, vol. XVI, p 239.

It is noteworthy that the reported occurrences of copper ores in Connecticut are all from the west side of the area. None of the occurrences are in strata above the main sheet of the contemporaneous traps. Closely parallel with this is the distribution of copper ores in the Triassic of New Jersey. Professor J. V. Lewis writes:—"The copper lies in irregular areas of the shales, between the intrusive and the lowest extrusive sheet. Sometimes it lies on the back of the intrusive, sometimes at the bottom of the earliest extrusive, but frequently it occurs with small dikes, or no visible trap at all, in the intervening areas of shales."

In several particulars the geological and mineralogical relations of the copper ores in Connecticut are analogous to those of the copper in the Lake Superior region. In each case there is an alternation of fragmental strata with contemporary sheets of igneous rock. In each case the copper ores are found partly in veins, and partly irregularly disseminated in both the sedimentary and the igneous rocks. In each case the occurrence of native copper is noticeable, though in the Connecticut area the amount of native copper as compared with other copper ores is much smaller than in the Lake Superior region. In two respects, indeed, the two regions are markedly different. The Lake Superior rocks are believed to be pre-Cambrian, and are, therefore, vastly more ancient than the rocks of Connecticut. Economically, the Lake Superior copper deposits are of immense importance. In Connecticut, on the other hand, none of the localities where mining has been attempted have yielded sufficient return to justify the continuance of operations; and most of the occurrences of native copper are noticeable merely as mineralogical curiosities. The analogy of the two formations in so many respects suggests that the cause of the copper deposits is probably the same in both cases. In each case it seems probable that the copper was brought up from a subterranean source in the igneous rocks, and that it has been subsequently concentrated in veins and local impregnations of the rocks by the chemical action of subterranean waters. As to the date of the formation of the

veins and other secondary deposits, we have no definite knowledge. It is, however, natural to associate these formations with the epoch of uplifting and faulting which followed the deposition of the sandstones.*

DEFORMATION.

There is reason to believe that the Connecticut Valley was defined as a geosynclinal trough between uplifts of Archæan rocks before the beginning of Paleozoic time.† The early history of the region is, however, obscure because of the imperfection of our knowledge of the age of the crystalline rocks. In the first chapter of this paper, an attempt has been made to picture the condition of the Connecticut Valley at the beginning of the Triassic.‡ At that time the Connecticut Valley trough is supposed to have been a shallow estuary, into which was carried by rivers the debris from the more or less degraded but still perhaps lofty mountain regions to the east and west.

As it is certain that all the Triassic strata were shallow-water deposits, and that, nevertheless, the strata have accumulated to a thickness of thousands of feet, it is obvious that the bottom of the trough must have been gradually sinking during the period in which the deposition was in progress. Such a gradual subsidence of the bottom of a trough may be effected either by folding or by faulting, or by some combination of the two actions. The fact that in general the dips of the sandstones are somewhat higher on the western than on the eastern side of the valley, suggests the probability that the subsidence during the Triassic era was effected, in part, at least, by a gentle downfolding of the crust. If such a movement took place, the strata on the

* Professor W. M. Davis writes in regard to the barite veins, that the barite "occurs at various points associated so closely with the faults that it may be safely stated as later than the eruptions, and associated with the tilting and faulting, or of still later date." Professor J. V. Lewis writes in regard to the copper ores of New Jersey: "I am pretty strongly inclined, at the present stage of the investigation, to consider the copper deposits as contemporaneous with or following closely upon the intrusion of the Palisades sheet, and the Rocky Hill, Sourland, and other sills to the southwest, and considerably later than the surface flows of the Watchung Mountains, possibly even as late as the disturbances that tilted and faulted the Triassic strata."

† *Dana, Manual of Geology*, 4th edition. p. 461.

‡ Page 24.

west side of the trough would have acquired a slight easterly dip before the movement at the close of the Triassic by which the whole formation was tilted. The western strata should therefore at the present time show a somewhat steeper easterly dip than the eastern ones.

Post-Triassic Movement.— At the close of the Triassic the character of the movement changed. The region was elevated above the sea level, and the estuary was drained. The elevation was greater on the west side than on the east, so that, apart from local irregularities, the strata in Massachusetts and Connecticut show a monoclinal structure dipping to the east.

While the general attitude of the Triassic strata in the Connecticut Valley is that of a monocline, careful study has revealed a considerable amount of local irregularity. In some places a crumpling of the strata into shallow boat-shaped or dish-shaped synclines is observed. This synclinal arrangement is the cause of the very strong curvature in the outcrop of the main trap sheet in the ridges of Saltonstall Mountain and Totoket Mountain.* Between these two synclines an anticline brings the underlying shales to the surface. In each of these cases, the eastern side of the boat, as we shall see hereafter,† was carried up by a fault above the level of erosion of the country, and so has been removed. A similar boat-shaped syncline, though less strongly marked, is indicated by the curvature in the ends of that long section of the main trap range extending from the Hanging Hills of Meriden to Mount Holyoke. The syncline of Totoket Mountain is further complicated by a transverse anticlinal crumple, which divides the posterior trap sheet into two parts, bringing up between them the underlying strata. A well-marked anticlinal axis shows itself, trending from west-northwest to east-southeast, in Wethersfield and Rocky Hill. By means of this anticlinal flexure the posterior sheet corresponding to Cedar Mountain is divided into two parts, the northern part with the associated stratified rocks

* See map, Fig. 1, page 19.

† Page 213.

dipping to the northeast, and the southern part dipping to the south. Careful study reveals a good many local irregularities of dip; yet, in spite of all these minor irregularities, it remains broadly true that the attitude of the strata is a monocline with a dip of 15° or 20° a little south of east.

Faults.— One of the important discoveries which we owe chiefly to Professor Davis is the detection of a large number of faults in the Triassic strata, in some of which there was a differential movement amounting to more than a thousand feet. The existence of extensive faults in the strata is rendered *a priori* probable by the immense thickness which it would otherwise be necessary to assign to the formation. A simple inspection of Fig. 7 will show the

Fig. 7. Method of Estimating the Thickness of Strata.
BC (thickness of strata)=*AB* (breadth of outcrop) × sine *A* (sine of angle of dip).

method of estimating the thickness of strata. *AB* in the figure represents the breadth of the formation measured in the direction of the dip; and it is obvious that, if there has been no dislocation of the strata, the thickness of the strata, *BC*, will be equal to *AB* multiplied by the sine of the angle of dip (the angle *A*). If we proceed to apply this mode of calculation to the Triassic of the Connecticut Valley, we get a very surprising result. In some parts of the valley the formation has a breadth of more than twenty miles; and, as we have already seen,* it is certain that the original breadth of the formation must have been somewhat greater than it is at present, since erosion must have removed more or less from the edges of the area. The natural sine of 20° is a little more than one-third, and even that of 15° is more than one-fourth, so that this geometrical construction would require a thickness of strata amounting to from five to eight miles. The subsidence of a trough probably not

* Page 167.

much more than a score of miles in breadth to a depth of even five miles, though it cannot be called impossible, would certainly be *a priori* improbable. The hypothesis of ex-

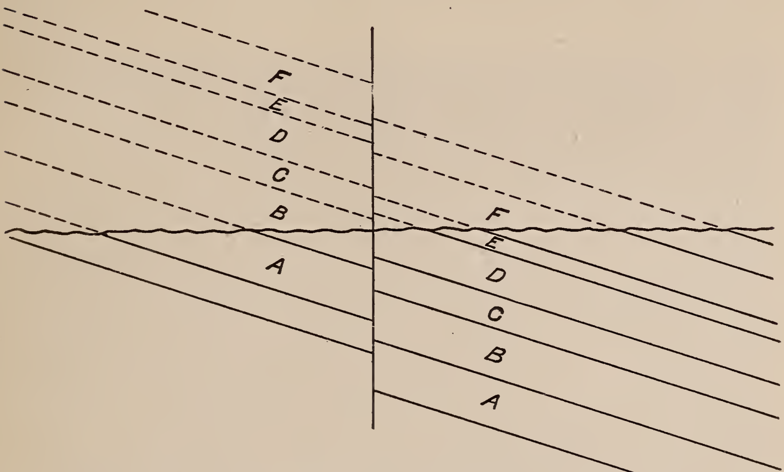


Fig. 8. Fault with dip side going down. Stratum *C* has no outcrop

tensive faults is the only one by which we can be relieved of this demand for an enormous thickness of strata. An inspection of Figs. 8 and 9 will show that the effect of faults

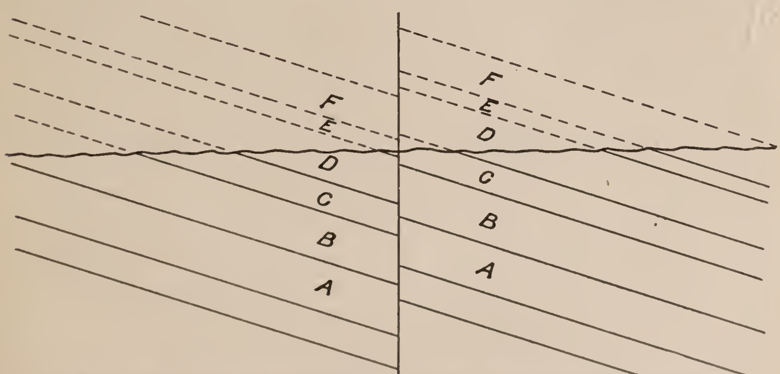


Fig. 9. Fault with dip side going up. Strata C and D have two outcrops.

upon the outcrop of strata varies according as the dip side or the outcrop side of the fault goes up. In each of these figures the surface of erosion is indicated

by an irregular line approximately horizontal, and the parts of the strata removed by erosion are indicated by dotted lines. Fig. 8 shows that if the dip side (*id est,* the side toward which the strata dip) goes down, more or fewer of the strata fail to reach the surface and to show outcrops. On the other hand, if the dip side of the fault goes up (as shown in Fig. 9), more or fewer of the strata come to the surface twice and present outcrops in two different places.* It is obvious, then, that the existence of faults, if due allowance were not made for them, would vitiate the computation of the thickness of a formation based upon its breadth and its angle of dip. Faults in which the dip side went down would diminish the breadth of the formation and would make the estimate of its thickness too small. Faults in which the dip side went up would exaggerate the breadth of the formation and make the estimate of the thickness excessive. If, then, there are, in the Connecticut Valley region, a number of faults in which there has been relative elevation on the east side, the astonishing estimate of a thickness of five miles or more, which we have provisionally reached, would be shown to be largely in excess of the truth.

Evidences of Faults.— But belief in the existence of numerous faults, with upthrow in the large majority of cases on the east, does not rest merely upon *a priori* conjectures. In the first place, there are a good many natural or artificial sections of the strata, exposed in ravines, quarries, roadside cuttings, and other places, where faults can be directly seen. The strata, as shown in plate XXII, on opposite sides of the crack do not match. In most of the cases where faults can thus be seen in an exposed section, the amount of the throw of the faults appears to be only a few inches or a few feet. In some cases, it is impossible to recognize corresponding layers on opposite sides of the crack, and therefore impossible to make any estimate of the amount of throw. But there is no reason to believe that the

* These rules are reversed when the plane of the fault lies in the acute angle between the horizontal plane and the plane of stratification.

PLATE XXII.

FAULTS IN SANDSTONE, MERIDEN.

Photograph taken under direction of W. M. Davis for U. S. Geological Survey.

throw is at all considerable in any of these visible faults.

In some cases, the presence of a fault is indicated by a somewhat nearly vertical zone of shattered and more or less decomposed rock, a few inches or a few feet in width, cutting across the rocks exposed in a natural or artificial section. Such a breccia would naturally result from the grinding action of the rocks on opposite sides of a crack in slipping past each other. But, while the presence of a band of fault breccia would indicate a fault, it would not show the amount of the throw or the direction of the movement. Similar to the evidence afforded by fault breccias is that afforded by *slickensides,* which are more or less polished and striated surfaces produced by the mutual grinding where rocks have slid past each other. A little more indirect is the evidence of faulting that is afforded when we find, in following the outcrop of a rock along the line of strike, that the rock suddenly disappears and is succeeded by a rock of totally different character, though the actual contact of the two rocks is concealed by drift or vegetation. If we walk northward along the ridge of coarse sandstone just east of the Agricultural Fair grounds in Meriden, we shall find that the sandstone ridge presently disappears abruptly, and a great mass of trap rises directly before us. In this case no actual contact of the two rocks can be found; but the collocation of the rocks hardly admits any other interpretation than that of a fault.

An evidence of faults, which would not be in itself conclusive, but which helps to locate the position of a fault when its existence is indicated by other evidence, is found in abnormal dips. There is no sharp line of demarkation between faults and monoclinal flexures. If rocks are subjected to the action of forces which tend to make the portion on one side of a line move relatively upward and the portion on the other side of that line move relatively downward, the yielding may take place by the bending and stretching of a portion of the rock into a steeply dipping monocline along the line of differential movement, or the rocks may crack under the strain and a fault be produced.

The two actions may be combined, and we may have on the upthrow side of the fault a downward bending, and on the downthrow side of the fault an upward bending of the edges of the strata. The presence, then, of abnormal dips (" drag dips "), in situations where other evidences have led us to believe in the existence of faults, may serve for the more definite location of those faults.

Professor Davis has rightly urged, as an evidence of great faults in the strata, the immensely improbable series of coincidences in the stratigraphy which we should otherwise be compelled to assume. All along the Connecticut portion of the Triassic area, we find three sheets of trap presenting parallel outcrops, the lowest a comparatively thin sheet, the middle one a thick sheet, the upper one again a thin sheet. Between the lower or anterior sheet and the main sheet lies a series of rocks, mostly red shales, but including a thin stratum of limestone and a thin stratum of black shale with fossil fishes. Between the main sheet and the posterior sheet we find again a series of shales, mostly red, but including a stratum of black shale containing fossil fishes which are only in part specifically identical with those of the black shale below the main sheet. Below the anterior sheet and above the posterior sheet lie great accumulations of sandstones, shales, and conglomerates. Now, whether we make a section across Totoket Mountain or Higby Mountain or Lamentation Mountain or the long range which extends northward from the Hanging Hills, we encounter the same succession — underlying sandstones, then a thin sheet of trap, then shales, which in many different localities have been shown to include a stratum of limestone and a stratum of black fossiliferous shale, then a thick sheet of trap, then shales again, including a stratum of black fossiliferous shale, then a thin sheet of trap, then overlying sandstones. Now, the repetition of this identical stratigraphic series again and again is intelligible if we assume that the strata themselves are identical — that the thick sheet of trap in the Hanging Hills and in Lamentation and in Higby and in Totoket is the same sheet of trap, only

dislocated by faults, and that the successive members of the series, underlying and overlying the main trap sheet, are likewise identical. But on any other supposition it requires us to assume a series of coincidences in the order of sedimentation and igneous eruption which would be immensely improbable.

Topographic Effect of Faults.— An indirect but very satisfactory evidence of the faults in the Triassic formation is found in their topographic effects. Of course the primary effect of a fault upon the topography is to produce an elevation of the surface on one side of the crack above the other, showing, if the plane of the fault be somewhat nearly vertical, a more or less decided cliff. If the fault

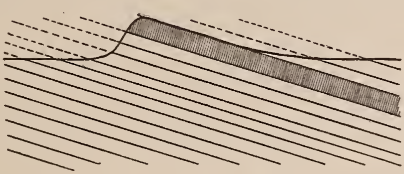


Fig 10. Section showing Monoclinal Ridge developed by Erosion. The shaded stratum is more resistant than the others.

were accomplished by an instantaneous movement, the height of that cliff would be equal to the amount of throw of the fault. In subsequent time the tendency of erosion would be to diminish the height of the fault cliff and ultimately to efface it. Probably a fault cliff of the full height due to the throw of the fault nowhere exists, since it must be presumed that no large fault is ever produced by a single instantaneous movement, and the agencies of erosion would therefore be in action for a greater or less time before the fault was complete. As we have already seen,* the region of the Connecticut Valley was reduced to a peneplain in late Mesozoic time, and not a vestige of a fault cliff is to be found anywhere in the Connecticut Valley.

But, while the direct topographical effects of the faults in the Connecticut Valley have entirely disappeared, in-

* Page 28.

direct effects have been produced which we can very clearly recognize. In Fig. 10 is seen a section of a series of monoclinal strata. The shaded stratum is supposed to be more resistant to the agencies of erosion than the others. The section shows the topographical effect of such a structure. The outcrop of the strong stratum is marked by a ridge, with gentle slope in the direction of the dip and with steep slope on the other side.* It is needless to say that it makes no difference in the topographic effect whether the strong member of the stratigraphic series is a hard stratum of sedimentary rock or a sheet of igneous rock. In Fig. 11

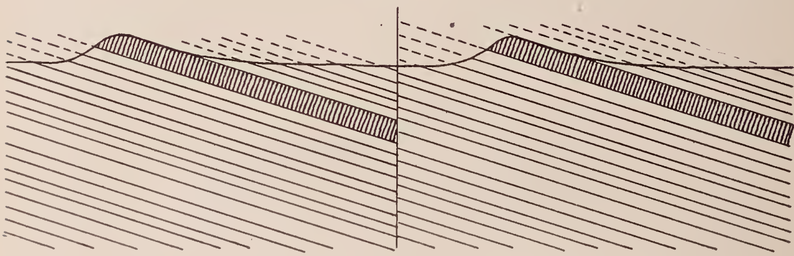


Fig. 11. Section showing two Monoclinal Ridges developed from the same Resistant Stratum, which has two outcrops by reason of a fault.

is seen the effect of a fault parallel to the strike and with upthrow on the dip side. A number of strata, among them the strong, ridge-making stratum, have their outcrops duplicated, and the section accordingly shows two ridges instead of a single ridge. It is evident that, if the fault is parallel to the strike, the two ridges thus formed by the outcrop of the resistant stratum will extend indefinitely as parallel ridges. But if the fault is at right angles with the strike, as shown in plan in Fig. 12, it is evident that each of the two parallel ridges will end abruptly at the fault plane without overlapping. Figs. 13 and 14 show the effect of diagonal faults. Where the rocks have been acted upon by a diagonal fault, the strong stratum develops, as before, two parallel ridges, each cut off on the fault plane. In Fig. 13, in which the dip side of the fault goes up, the two parallel ridges overlap each other for a certain distance; while in

* See also Plates II, XIX, XXIII.

Fig. 14, in which the dip side of the fault goes down, we have what we may call a case of negative overlap, the ridge due to the outcrop of the strong stratum disappearing for a certain distance. If we study a little more in detail the

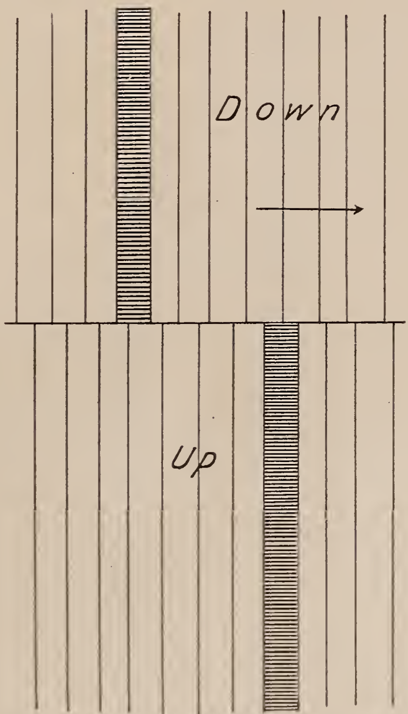


Fig. 12. Plan of Strata with Fault perpendicular to the Strike. The arrow indicates the direction of the dip. The parallel ridges which may be developed by erosion along the outcrops of a resistant stratum will be truncated at the fault line without overlapping.

conditions shown in Fig. 13, we shall see that the two ends of the overlapping ridges will not be exactly alike in their topographic expression. In the conditions represented in that figure — a dip to the east, and a northeast and southwest fault with upthrow on the southeast side — it is obvious that the acute angle shown on the plan at the south end of the strong stratum on the northwest side of the fault lies nearly in the line of the crest of the ridge; while, on

the southeast side of the fault, the obtuse angle shown at the north end of the southern part of the strong stratum lies in the line of the crest of the ridge, and the acute angle lies low down on the back of the ridge. The effect of this arrange-

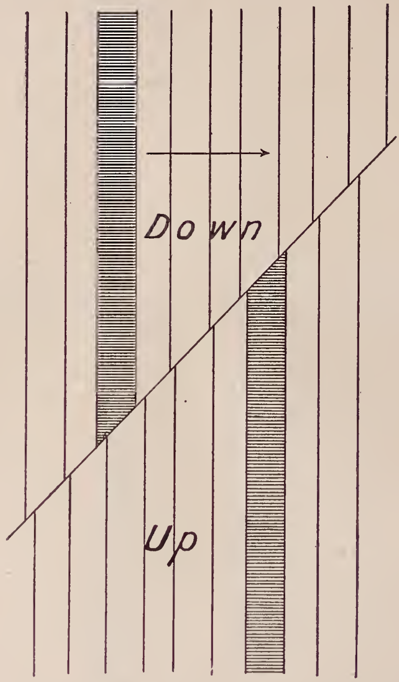


Fig. 13. Plan of Strata with oblique Fault and with the dip side going up. In this case the parallel ridges developed along the outcrops of a resistant stratum will overlap.

ment would be that, in such a case as is represented in the figure, the ridge on the north side of the fault must end southerly in a bold bluff, while the ridge on the south side of the fault must end northerly in a long trailing slope. A striking illustration of this last point may be seen in comparing the tapering north end of Higby Mountain with the bold southern cliff of Chauncey Peak (the southern part of the range of Lamentation Mountain). This picturesque peak is shown in Plate XXIII. Plate XXIV is a map of the middle part of the Connecticut Triassic area, showing the

PLATE XXIII.

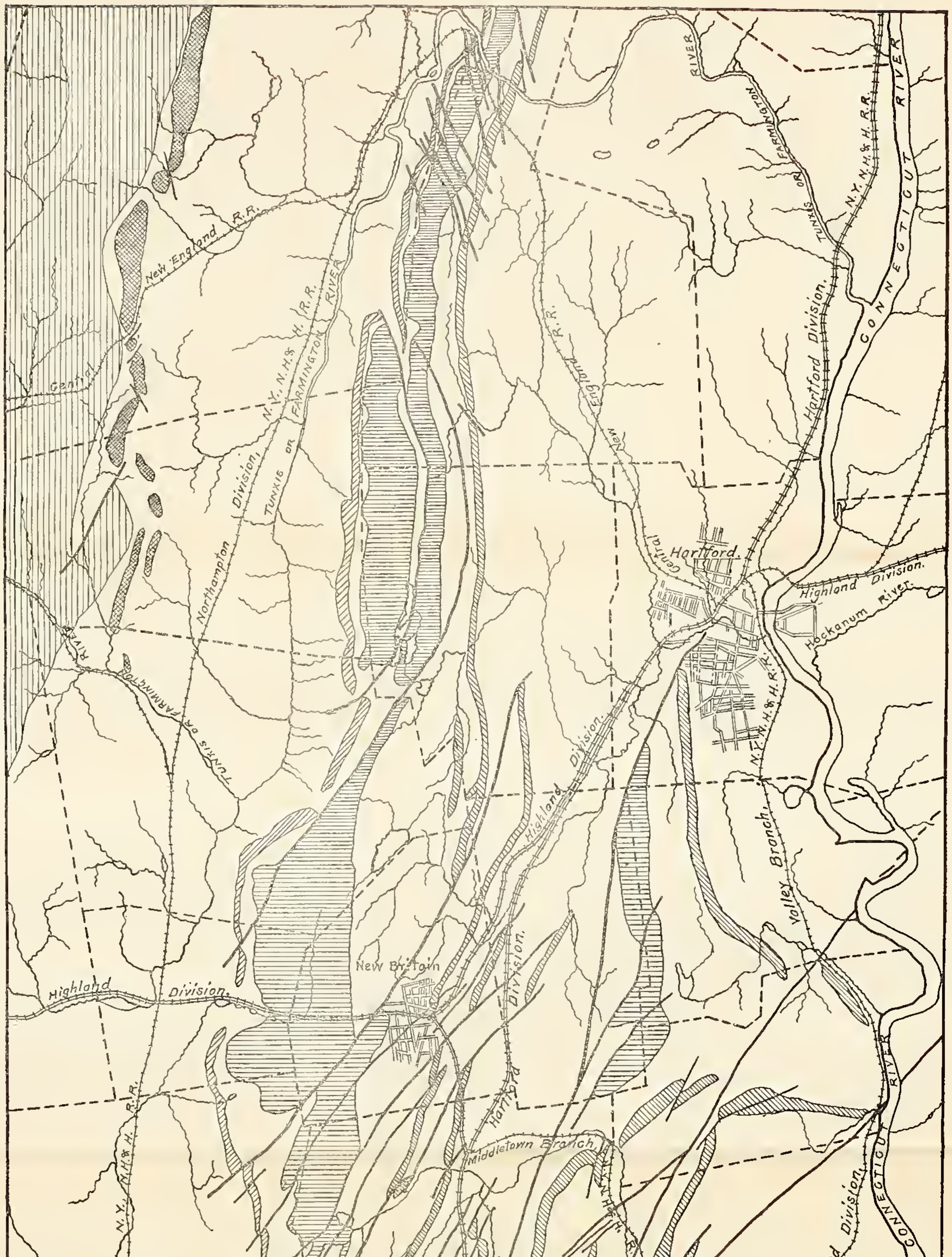
CHAUNCEY PEAK, MERIDEN.

The abrupt cliff at the right is due to the Lamentation-Higby fault.
Photograph taken under direction of W. M. Davis for U. S. Geological Survey.

MAP SHOWING TRAP SHEETS AND FAULTS IN CENTRAL PART OF TRIASSIC AREA OF CONNECTICUT.

From map by W. M. Davis in *Eighteenth Annual Report of U. S. Geological Survey.* (Slightly altered.)

PLATE XXIV.



MAP SHOWING TRAP SHEETS AND FAULTS IN CENTRAL PART OF TRIASSIC AREA OF CONNECTICUT.

From map by W. M. Davis in *Eighteenth Annual Report of U. S. Geological Survey.* (Slightly altered.)

principal faults; and, though no contour lines are given on the map, the reader, remembering that the main trap sheet is the ridge-making member of the formation, can see how beautifully the topography interprets itself on the hypothesis of a great series of faults.

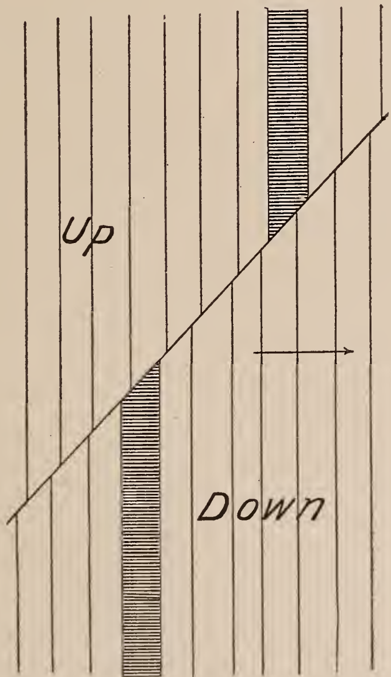


Fig. 14. Plan of Strata with oblique Fault and with the dip side going down. In this case the parallel ridges developed along the outcrops of a resistant stratum will show a negative overlap.

It may be remarked incidentally that the faults which have broken the continuity of the main trap ridge have had an important influence in the commercial and industrial life of the state, by making practicable railroad routes from the eastern to the western side of the Lowland. The fault which lies between the Hanging Hills and Lamentation Mountain permits the passage of the Hartford Division of the New

York, New Haven, and Hartford Railroad between Berlin and Meriden; the fault between Lamentation Mountain and Higby permits the passage of the Meriden Branch between Middletown and Meriden; and a little fault which dislocates Saltonstall Mountain allows the passage of the Shore Line Division between East Haven and Branford.

It is easy to determine the location of the faults very accurately where they cross the outcrops of the trap sheets, and particularly where they cross the outcrops of the main sheet. That massive sheet of trap is everywhere a conspicuous feature in the topography, and it has an individuality which is readily recognizable. In the sandstones, the location, with any degree of definiteness, of faults which cannot be directly observed, is practicable only in those places where abnormal dips indicate the drag of a fault. The sandstones and shales oppose in general but a weak resistance to erosion, and have therefore been degraded in most places towards the condition of a peneplain, which is for the most part covered by drift and vegetation. Even where outcrops of the sandstones and shales are to be found, they generally have not sufficient individuality to be recognized as belonging to any particular horizon within the formation. In the monotonous variety of beds, some coarser, some finer, some redder, some grayer, there are none that have any recognizable individuality excepting the thin strata of limestone and black shale; and those beds are so weak that their outcrops are very scanty indeed. Presumably many of the faults that have been recognized in the Triassic formation extend beyond the limits of the Triassic into the crystalline rocks on one or both sides of the Connecticut Valley; but the recognition of faults in the crystallines is difficult and uncertain on account of the extreme complexity of structure of the crystalline rocks. The plotting of faults on the map, Plate XXIV, is therefore inevitably to a considerable extent hypothetical. It should also be noted that, where a fault line on the map comes to an end, the meaning, in general, is not that we have proof that the fault comes to an end at that particular

locality, but only that our knowledge of it comes to an end.

Direction of Faults.— South of Hartford the prevailing direction of the faults is northeast and southwest. In the latitude of Hartford, the direction of the faults becomes nearly north and south, and still farther north the faults show predominantly a northwest and southeast trend. Throughout the area, at least the Connecticut portion thereof, the upthrow is on the east side in a very large majority of cases.* Among the most interesting faults are the two large ones which lie, respectively, between the Hanging Hills and Lamentation, and between Lamentation and Higby. With a considerable degree of probability these two faults can be traced across the entire breadth of the Lowland. Dislocations of the intrusive sheet on the west margin of the area, and dislocations of dikes in Cheshire and Wallingford, lie nearly in the line of these faults, produced southwestward; and two considerable portions of the eastern boundary of the Triassic area lie nearly in the line of the continuation of these faults at the northeast. Between the Hanging Hills and Lamentation, Davis estimates the upthrow on the southeast as not less than 2,000 feet, and between Lamentation and Higby as not less than 1,300 feet. Talcott Mountain is situated just in the latitude where the northeast and southwest trend changes, through north and south, to northwest and southeast. The peculiar double-ridged form of Talcott Mountain is due to the fact that for a considerable distance the trend of a fault plane is nearly parallel to that of the strike of the strata and the consequent trend of the range.

In the vicinity of a great fault it is often the case that a number of little faults may be observed. Sometimes there will be a series of step faults parallel with the main fault; and, again, the slices into which the rock is broken by such a series of parallel faults may be still further dislocated by

* In the region of Mount Tom, Emerson notes a series of faults with upthrow on the west side. *Geology of Old Hampshire County*, p. 449.

cross faults. In the vicinity of East Berlin the great fault that lies between the Hanging Hills and Lamentation appears to be broken into parallel faults, while the structure is further complicated by a number of little cross faults. The structure of this interesting locality is shown in the sketch map, Fig. 15. In this case it is obvious that the faults

Fig. 15. Sketch map showing Faults near East Berlin. Scale, 1200 feet to the inch. Outcrops of shale and sandstone shown by horizontal lines, outcrops of trap by oblique cross lines. Faults shown by dotted lines. Dip and strike shown by the sign T.

can be definitely located only at a few points where trap and sandstone are found almost or quite contiguous along the line of strike, or where trap outcrops end abruptly, or where the sandstones present abnormal dips. The tracing of the fault lines at a distance from these critical points must be, of course, merely hypothetical. The cutting on the Meriden Branch of the New York, New Haven, and Hartford Railroad just west of Westfield station shows three

Fig. 16. Faults with Drag Dips, north wall of railway cutting, Westfield. Scale 44 feet to the inch. At the west end the stratified rocks are overlain by trap.

faults of unknown, but probably inconsiderable, throw, clearly marked in the section exposed in the wall of the cutting by the discontinuity of the strata and by steep northwesterly dips (drag dips), while the proximity of the great fault between Lamentation and Higby is indicated by the slight northwesterly dip of the whole section (see Fig. 16). There is good reason to believe that the faults which actually exist in the rocks are much more numerous than those which have been detected and of which the principal ones are shown on the map. In Professor Hobbs' work on the Pomperaug Valley, the numerous faults by which the traps of that little region are dislocated are traced most minutely and with consummate skill.

Marginal Faults.— There is strong reason to believe that the present eastern border of the Triassic area of Connecticut is due almost entirely to a series of faults. This belief is founded on a variety of evidences. From New Haven to Durham the eastern boundary of the Triassic formation crosses the synclines of Saltonstall Mountain and Totoket Mountain, the anticline between them, and the minor anticline in the middle of the Totoket syncline. If the surface of contact between the crystallines and the sandstones were the surface of the crystallines upon which the sandstones had been deposited — a surface which must be supposed to have sloped gently westward,— then the effect of a crumpling of the rocks into alternating anticlines and synclines must have been to make the line of intersection between the contact surface and the nearly horizontal plane of erosion strongly sinuous. The boundary would have been thrown into

curves convex towards the sandstones on the anticlines and convex towards the crystallines on the synclines. In fact, however, the boundary is not far from a straight line; and the slight curves which it shows are not in accordance with the rule stated above. The only effect of the folding is that on the anticlines lower members of the Triassic series abut upon the crystallines, and on the synclines higher members. The nearly straight boundary, in fact, cuts across all members of the Triassic series, from the sandstones underlying the anterior trap sheet to the sandstones overlying the posterior sheet. This relation is only intelligible on the supposition that the actual surface of contact between the sandstones and the crystallines is not far from a vertical plane. It must be assumed, then, that the boundary from New Haven to Durham is determined by a fault with upthrow on the east. The former continuation of the Triassic eastward of this fault line was carried up above the plane of erosion, and has therefore been removed. In Glastonbury and in Vernon two sections of the eastern boundary of the formation lie nearly in the line of the two great faults which separate, respectively, the Hanging Hills from Lamentation and Lamentation from Higby. In the vicinity of the eastern boundary of the Trias, in many localities, both the sandstones and the crystallines show strong indication of disturbance. Abnormal and excessive dips are frequently observed in the sandstones. The strata are very much jointed, and oftentimes shattered by a perfect confusion of little faults. The crystallines near the boundary show in many places a peculiar brecciated structure, and the presence of much chlorite. Near the Highland Park paper mill, in Manchester, the digging of a trench revealed a fault contact between the sandstones and the crystallines, the fault plane dipping 55° to the west.* While it is obvious that the evidence is not equally conclusive for all parts of the boundary, there is, on the whole, strong reason to believe that the eastern boundary is formed in the main by a series of faults. In parts of the

* Davis and Griswold, in *Bull. Geological Society of America*, vol. V, p. 526.

western boundary there are irregularities which can only be interpreted as the result of faults. In a few cases it seems probable that faults by which the trap ridges are dislocated find their continuation in small sections of the western border. In the main, however, the western boundary is remarkably straight, and there is nothing in its character that requires the assumption of a marginal fault, though it is possible that the western boundary, like the eastern, may be mainly determined by fault lines. The relations of the sandstones and crystallines at the old copper mine near Bristol, as described by B. Silliman, Jr., and J. D. Whitney,* require the assumption of a fault with upthrow on the west. Those geologists who believe that the Triassic formation extended originally much beyond its present limits, are disposed to consider the Connecticut Valley as a *graben* — i. e., a region which has slipped down between two faults. While there is nothing in the phenomena observable in most parts of the western border which requires the supposition of a fault with upthrow on the west, there is nothing which positively excludes that hypothesis. As we have already seen, a very large majority of the faults which can be proved to exist in the Connecticut Valley area have their upthrow on the east. There are, however, some exceptional cases in which the upthrow is on the west.

Professor Hobbs has shown good reason for believing that the Pomperaug Valley basin is essentially a graben, and that that little remnant of the Triassic owes its preservation to having dropped down between its bounding faults below the plane of erosion. There is more or less evidence that the other Triassic areas of eastern North America have their limits determined wholly or partially by marginal faults.†

Thickness of the Triassic Strata.— The proof of the existence of numerous faults with upthrow to the east relieves us, as we have already seen,‡ of the necessity of assuming

* *Am. Journal of Science*, series 2, vol. XX, p. 361.

† Hobbs, *Former Extent of the Newark System*, in *Bull. Geological Society of America*, vol. XIII, p. 142.

‡ Page 201.

an enormous thickness for the Triassic strata. On the other hand, the probability that numerous faults exist which are entirely undetected, or the amount of whose throw is unknown, renders it impossible to determine with any accuracy the correction which must be applied to make the trigonometric computation of the thickness of the strata yield a just result. It seems probable, however, after all allowances are made, that the formation is of great thickness. Among other indications pointing in this direction may be mentioned the great depth of some of the wells which have been bored in the sandstones without reaching the underlying crystallines. The depths of a few of the deepest of these are as follows:— Hartford, 1,250 feet; Forestville, 2,000 feet; Northampton, 3,700 feet; New Haven, 4,000 feet.* The aggregate of Davis' estimates of the probable thickness of the various members of the formation is from two to two and one-half miles.†

Dynamic Theory of the Structure.— Can we give a dynamic interpretation of the present attitude of the Triassic formation — its general monoclinal position, and its numerous dislocations? It must frankly be confessed that our knowledge of the dynamics of earth movements is too meager to justify dogmatic statements. But it seems legitimate to venture tentatively a little way in the direction of dynamic explanation.

It is a noteworthy fact that the monoclinal structure which is observed in the Connecticut Valley prevails also in the other Triassic areas. But in the Acadian, New York-Virginia, Richmond, Danville, and Dan River areas the prevailing dip is to the northwest, while in the Connecticut Valley, Deep River, and Wadesboro areas the prevailing dip is southeast. If a somewhat sinuous line is drawn from Massachusetts to North Carolina between the areas of northwest dip and the areas of southeast dip, as shown in Plate XV, that line will, in a general way, be parallel to the trend of the mountain ranges which mark the eastern border of the American continent. It is reasonable

* Gregory, *Farmington Folio*, U. S. G. S.

† *Eighteenth Ann. Rep. U. S. Geological Survey*, vol. II, p. 28.

to suppose that the northwest and southeast dips on opposite sides of this axial line find a unitary interpretation in the conception of a broad and gentle upfolding of the crust of the globe. Such a broad and gentle upfolding, involving the crust of the globe down to an unknown depth, has been called by Dana a geanticline, in distinction from those more narrowly local and often much steeper folds of particular groups of strata which are called anticlines.* The cause of such a geanticlinal movement is most probably to be sought in the cooling and consequent contraction of the interior of the globe, producing tangential strains in the crust, to which from time to time the crust yields in great wrinkles. Where such a geanticlinal movement produces a permanent elevation, the mountain range thus formed has been called by Dana an *anticlinorium.*† The most fundamental conception then, of the crustal movement which produced the monoclinal arrangement of the strata in these Triassic basins is that a broad zone of the eastern border of the continent was elevated by tangential pressure into a great geanticline. But apparently such a geanticlinal movement is apt to be associated with faulting. The broad, flat arches are apt to crack, and the blocks into which the arches are broken to slip past each other in obedience to gravitation until they find themselves in stable adjustment. In this view the differential movement of the blocks in faulting must be attributed to gravitation. Some parts of the broken arch sunk lower than other parts. There is probably no such thing as the vertical upheaval of large areas of the crust of the globe. The only force acting on a large scale in a vertical direction is gravitation, and that acts always downward. In the broad view, then, of the dynamics of the crustal movements evidenced by the structure of the Triassic for-

* The recognition of such a geanticline is of course entirely independent of the question whether the Triassic formation ever extended across the axis or not.

† *Am. Journal of Science*, series 3, vol. V, p. 4[illegible]2. The word anticlinorium has been used by some recent writers in a different sense (See *Am. Journal of Science*, series 4, vol. II, p. 168; *Science*, vol. XXIII, p. 286.) The more characteristic type of mountain-making movement is the formation of a downfold of the earth's crust (geosyncline), the accumulation of a vast thickness of strata in the trough, the weakening of the lower strata of the trough by internal heat, and the final crushing of the rocks into a series of anticlines and synclines. Orogenic movements of this type occurred in eastern North America in post Archæan, post-Ordovician, and post-Carboniferous time. (See p. [illegible]3.)

mation, we must attribute the formation of the great geanticlinal arch to tangential pressure in the crust, probably arising from the cooling of the globe, while the differential movement of the blocks into which that arch was broken along the fault planes must be attributed to gravitational readjustment. It is evident that, if the faulting was due to gravitational readjustment of the blocks into which a geanticline was broken, the natural expectation would be that on the southeastern side of the geanticlinal axis the great majority of the faults would have their upthrow to the southeast. The greatest sinking in such gravitational readjustment would naturally be near the axis of the geanticline. It will be recognized that this corresponds well with the facts which have been observed in regard to faults in the Connecticut Valley. It is an interesting fact that in the Triassic of New Jersey, which lies on the northwest side of the supposed geanticlinal axis, the great majority of the faults have their upthrow on the west side.* The relations in Connecticut and in New Jersey are thus mutually complementary.

In the introductory chapter of this paper,† in the endeavor to picture the condition of Connecticut at the close of the Triassic, a comparison was made with the Great Basin of North America. There, at the present time, we have a topography whose features are chiefly determined by faults. A series of approximately parallel mountain ranges present on one side a steep face, which is determined by a fault plane, while there is a gentle slope on the other side. That obviously must have been the topography of the Connecticut Lowland after the post-Triassic uplift, and before the work of denudation in the later Mesozoic had reduced the region to a peneplain. In all probability the resemblance between the post-Triassic conditions in Connecticut and the present conditions in the Great Basin is not only phenomenal, but also dynamical. It is the most plausible interpretation of the structure of that region that the

* Kümmel, *in Ann. Rep. State Geologist N. J.*, 1897, pp. 105-136.

† Page 26.

whole area between the Sierra Nevada on the west and the Wasatch on the east was bent by tangential pressure into a broad geanticlinal arch, while, *pari passu* with the elevation, went on the fracturing of the rising arch and the gravitational readjustment of the blocks into which it was broken.

DRAINAGE.

It is an interesting question to what extent the present drainage system of the Connecticut Valley area finds its causes in the post-Triassic deformation which we have been studying.* The question is, however, one to which it is impossible to give a very definite answer. As has been already stated, in late Mesozoic time, substantially the whole area of Connecticut was reduced to a peneplain. It is possible and not improbable, though by no means certain, that the Cretaceous sediments which now exist on Long Island once extended northward to an unknown extent over southern Connecticut. No remnants, indeed, of Cretaceous strata have been found in Connecticut, but the amount of erosion which has certainly taken place is so great that the supposition of the complete removal of the Cretaceous formation is by no means incredible. How far the courses of Connecticut rivers may have been taken upon the surface of Cretaceous strata, and may now be superimposed upon the underlying Triassic sandstones and crystalline rocks, is entirely unknown.

The Tertiary uplift, which may be said to have initiated the development of the present topography of Connecticut,† seems to have been, like the post-Triassic uplift, a geanticlinal movement. It was apparently a broader geanticline, and its axis must have lain farther west. This movement, as we have seen, gave to the surface of Connecticut a decided slope from northwest to southwest. As the general direction of slope in this region due to the Tertiary uplift was about the same as that due to the post-Triassic uplift, the stream courses which appear to be consequent on

* See Davis, in *Eighteenth Ann. Rep. U. S. Geological Survey*, vol. II, pp. 144-184; Kümmel, *Some Rivers of Connecticut*, in *Journal of Geology*, vol. I, pp. 371-393.

† See page 29.

such a slope may date from either of these epochs. If they date from the earlier (post-Triassic) uplift, they must have persisted through the long cycle of late-Mesozoic erosion.

It seems, on the whole, probable that the course of the lower Connecticut across the eastern crystallines from Middletown to Saybrook was consequent upon the post-Triassic uplift. A river so large as the Connecticut would be very likely to maintain its course through a long series of geological changes.

Consequent also upon the post-Triassic uplift may have been the considerable river which doubtless once flowed through the gap in the trap range between Plainville and New Britain (Cook's Gap), and which must have received as tributaries the Farmington and the Pequabuck, or their earlier representatives. This gap has no relation to any known faults, and must have been the result of the erosive action of a river of considerable size. If the river which flowed through Cook's gap was consequent, as is possible, upon the post-Triassic uplift, it must have maintained its course through the late-Mesozoic cycle of denudation and until some time after the Tertiary uplift. The present gap in the trap ridge, we may be sure, was cut in Tertiary time, for a gorge carved in any earlier period would have been for the most part obliterated when the whole country was reduced to a peneplain. In the Tertiary cycle of erosion, a southward-flowing stream in the sandstones would have the advantage of an eastward-flowing stream, which had to carve a gorge across the trap sheet; and some time in the course of that cycle the waters of the stream which had flowed through Cook's Gap were diverted southward, west of the trap range, and probably found their way to New Haven along the present course of Mill River.

It is possible also that the post-Triassic uplift may have initiated the river that flowed across the trap range at Tariffville, and carved the gentle outer slopes of the valley within which in later time has been carved the narrow, steep-walled gorge through which flows the Farmington. In this case, as in the former one, if the river crossing the

trap sheet at Tariffville was initiated by the post-Triassic uplift, it must have held its course until after the Tertiary uplift. That river was certainly not the Farmington as it is to-day, but it may well have been a stream which received the waters of what are now the northern tributaries of the Farmington. Like the stream which flowed through Cook's Gap, the stream which crossed the trap range at Tariffville was diverted to the south in the course of the Tertiary cycle of erosion, and for the same reason. The Tariffville stream was in all probability a smaller one than that at Cook's Gap, and had not carved its valley to so low a level when it was diverted southward. In the later part of the Tertiary cycle of erosion there must have been a single river running in an approximately straight course from Granby to New Haven, including the northern tributaries of the Farmington, the middle part of the Farmington, a small section of the Pequabuck, the upper part of the Quinnipiac, and substantially the whole of Mill River. The dismemberment of this river, and the establishment of the present drainage system of the region, were undoubtedly due to events connected with the Glacial period — to deposits of drift, and possibly to slight differential movements of the earth's crust. It is undoubtedly these events which resulted in the reversal of the course of the middle Farmington and the lower Pequabuck, sent the Farmington through the old Tariffville valley across the trap range, caused the Farmington to cut the narrow inner gorge at Tariffville (whose aspect of extreme youth proclaims unmistakably its post-Glacial date), and diverted what had been the northern part of Mill River into the Quinnipiac, which cut a narrow (post-Glacial) gorge through the sandstone ridge in Meriden.*

Unlike the stream that flowed through Cook's Gap, the stream that, at the time of the post-Triassic uplift, took its course across the trap at Tariffville, probably had its location determined by a fault. At present, indeed, as shown on

* For fuller discussion of the effects of Quaternary events upon the drainage of the Farmington-Quinnipiac Valley, see page 251 and Figs. 20-22.

the map, Plate XXIV, the Farmington River cuts across the southern extremity of the section of the main trap sheet northeast of the fault. But, as shown by Kümmel,* the river probably flowed originally directly through the break in the line of outcrop of the main trap sheet at the fault. In the progressive degradation of the country the outcrops of all members of the formation — strata and trap sheets alike — would be shifted eastward. As a result of that shifting, the outcrop of the trap sheet northeast of the fault would extend farther southward than before, as shown in Fig. 17.

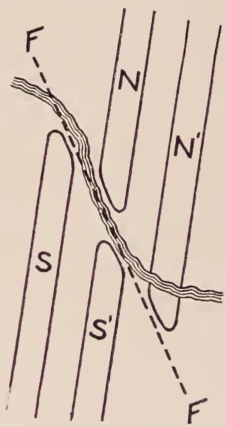


Fig. 17. Relations of Trap Sheet, Fault, and River at Tariffville. *F*, *F*, fault; *N*, *S*, trap outcrops north and south of fault before degradation; *N'*, *S'*, same after degradation.

In that way it came to pass that the course of the river crossed the outcrop of the main trap sheet northeast of the fault.

* *Journal of Geology*, vol. I, p. 386.

Chapter IV

Glacial Geology

By

HERBERT ERNEST GREGORY

GLACIAL GEOLOGY.

THE PROBLEM STATED.

The general topography of the northeastern part of the United States is quite unlike that of many portions of the earth's surface. There is a notable absence of rough and ragged contours, sharp crests, and projecting needles. The hills are rounded off and exhibit mammiform outlines. This is true not only of the higher and more prominent ridges, but also of the lower lands, where the surface presents a billowy appearance. In other parts of the country rocks of different types and different structure assume characteristic outlines — sinks and knobs in limestone, pyramids and mesas in horizontal strata, long even ridges in folded strata, etc.; rock structure and attitude being revealed in the surface configuration. In Connecticut and adjoining states, however, the rocks are rounded and smooth, regardless of their character, and at a distance it is scarcely possible to distinguish a hill of gneiss from one of trap or of limestone. Not only consolidated rock, but sands, gravels, and loose materials of various sorts are built into hills and ridges with undulating profiles.

Another feature which attracts the attention of one coming from the west or the south is the unusual abundance of bowlders of all sizes and shapes and materials, which are strewn widely over highland and lowland alike, as well as built into walls along the roadways.

Characteristic, also, of the scenery of this region, is the presence of numerous lakes and ponds picturesquely located on hills, in valleys, in woodland, and in field. The presence of numerous bodies of water of this kind would be a topographic feature unknown in many parts of the world. The Century Atlas shows no lakes in Delaware, Maryland, West Virginia, Kentucky, Tennessee, Alabama, or Kansas; they

are likewise very rare in many other states. In the same atlas, however, Connecticut is credited with 216 lakes large enough to be represented on the map, while the United States Topographic Atlas shows 1,026 lakes and 420 swamps within the borders of this one state.

If the soil of Connecticut be compared with that of some other sections of the United States it is seen to possess two chief characteristics: namely, remarkable variety within small areas, and lack of correspondence between the soil cover and the rock beneath. Here sandstone soil may cover granite ledges, and soil made of lava fragments may lie upon shales. In the South, limestone is covered with limestone soil, and decomposed shale is the cover of shale rocks.

Since rounded hills, abundant bowlders, numerous lakes, and soil unlike the rock beneath, are not universal phenomena, but are characteristic features of the surface of Connecticut, they clearly require some explanation not applicable to all parts of the earth.

Weathering and Decay of Rocks.— One naturally looks to the atmosphere as the cause of the decomposition of surface rocks and of the formation of soil and bowlders, as the source of the water in lakes and streams, and as the chief agent in molding the earth's topography. The atmosphere is by far the most important of geological agencies producing these results. It does not operate with great rapidity, but is everywhere present and has been at work ever since the rocks have existed at the earth's surface. The work of the atmosphere is expressed by the general term *weathering*, and the character of its results is seen when we compare blocks recently taken from the Portland quarries, with stones taken from the same place a hundred years ago and used as monuments in Connecticut cemeteries. The stone from the quarry is fresh; the tombstone has a dulled surface, and even its inscription may have been eaten away; that is, the rock has weathered. This action of the atmosphere on rock at the earth's surface varies with the character of the material. If the rock contains

such constituents as can readily be decomposed chemically by the gases of the atmosphere, it disintegrates rapidly. If it contains constituents which are more resistant, it crumbles slowly. In either case, however, it decomposes. If the rocks of the earth consisted wholly of extremely resistant material, *e. g.*, platinum, the atmosphere as now constituted would be practically powerless, and the land forms produced by the earth's cooling would be permanent as they now are on the moon. If, on the other hand, rocks were composed of less resistant materials, weathering would proceed at a more rapid rate, and the lands would be reduced to plains in a much shorter time. On our particular planet the relation between the action of the atmosphere and the resistance of the rock is such that *all rocks decay.*

If a rock belongs to the igneous class, like Connecticut granites or traps, decomposition takes place by means of selecting out certain minerals which yield more readily than others to the action of the atmosphere. For instance, granite, being composed of feldspar, quartz, and mica, has a vulnerable spot in the feldspar; and this is the point toward which the water from the atmosphere, carrying carbon dioxide and taking up humus acids from the soil, directs its attack. The feldspar is decomposed into clay, and the quartz and mica remain as loosened mineral fragments to represent the original solid rock. In the case of Connecticut sandstone, which is made up of grains of sand cemented by clay, iron oxide, or calcium carbonate, the cement is removed by atmospheric agencies, and the sandstone becomes once more a sand.

In this way solid rock is loosened and made more porous, and is rotted or decomposed down to a certain depth below the surface, the depth depending upon the character of the rock and the activity of the decomposing agents. A quarry in rock decomposed by the atmosphere shows a section from the surface to the bottom of the pit, in which the rock increases in solidity with the depth, and ranges from a loose-textured soil at the surface to firm, fresh building stone below. This variation in the section is due to the

fact that the work of the atmosphere is most effective at the surface and proceeds much more slowly and with less power as the depth increases. By this atmospheric action a loosened cover or mantle or sheet of rock waste is formed on the surface of the earth. It is not allowed to remain there indefinitely, but is being continually carried away. The result of unequal decomposition of different rocks and of variation in the rate of removal of the waste is that irregularities of surface, large and small, are found everywhere. The minor inequalities are concealed from view by the cover of decomposed rock, while the larger ones are shown in the hills, the valleys, and the plains.

The Soil of Connecticut.— Soil or rock cover of the nature just described is the ordinary surface mantle of the earth, but is not characteristic of New England. In fact, anywhere in Connecticut it would be difficult to find a section which showed for a considerable extent the gradual transition from rotted, loose rock above, to firm, fresh rock below. In the southern states the soil is formed out of the rock upon which it rests, and the transition from rotten to fresh rock is commonly seen in wells, quarries, and railroad cuts. In certain parts of the south the rotten rock extends down to a depth of ten, twenty, or even fifty feet, while in the tropics it reaches still greater depths. In Connecticut there is no gradual transition from soil to rock surface, but a layer of decomposed material rests directly upon firm, unchanged bed rock. The illustrations (Plate XXV) show these relations of soil to rock. That from the District of Columbia, shown in Fig. 1, represents the normal condition — a gradual increase in solidity with depth. The Connecticut view (Fig. 2) shows the abrupt change due to peculiar conditions. Generally, on the hills the soil is hard-pan; that is, a jumbled mass of bowlders, sand, and clay; in the valleys it is more apt to be sand and gravel in layers; but in either case the transition to rock below is abrupt. The character of the soil in Connecticut and its relation to the underlying ledge cannot, therefore, be a result of atmospheric action.

PLATE XXV.

FIG. 1. FORMATION OF SOIL IN A NON-GLACIATED REGION; WASHINGTON, DISTRICT OF COLUMBIA.

Transition is shown from soil to solid rock.
Photograph by G. P. Merrill.

FIG. 2. SOIL IN A GLACIATED REGION; ORANGE, CONNECTICUT.

Glacial soil rests directly upon solid rock.

PLATE XXVI.

FIG. 1. HILLTOP IN NON-GLACIATED REGION; PEAKS OF OTTER, VIRGINIA.
Photograph presented by Sidney M. Loyd.

FIG. 2. HILLTOP IN GLACIATED REGION; WEST PEAK, MERIDEN.

Bowlders.— The same may be said of the bowlders strewn broadcast over the state. They are found everywhere, not only in the valleys, but on the tops of the highest hills, oftentimes in great profusion. They are large or small, rounded or angular, and exhibit great variety in color, texture, and composition. They may be of the same rock as that which underlies them, but frequently are of widely different material, and when traced to their parent ledge are found to have been moved many miles to the southward. Bowlders may be formed by atmospheric agencies, but in such cases they possess features which unmistakably indicate their origin. Thus, they are of the same material as the unweathered rock near them, and partly formed bowlders of the same rock type still connected with the parent ledge are usually present. Such bowlders exist in great profusion at the tops of mountains and hills where the atmospheric gases and the frost are least hindered in their work. On Connecticut hill-tops, however, where the rock is exposed, it is not weathered into bowlders, but is commonly smooth and firm and fresh; if bowlders are present, they are plainly unrelated to the ledge. The difference in character between these hill-tops and those in regions where bowlders formed by rock decomposition prevail is strikingly shown in a comparison of the Peaks of Otter in Virginia with West Peak in Meriden. (See Plate XXVI.) As will appear later, West Peak was formerly covered with bowlders formed in place by weathering; but they have been removed and lost, and those which are now scattered over the surface have been brought from the region about Berlin Junction.

Lakes.—Furthermore, the atmosphere alone is not responsible for the great abundance of lakes and swamps within the state. This feature is common to a large part of the northeastern United States, but is not due to the rainfall. There is no necessary relation between the amount of rainfall and the presence of lakes. Kentucky, with no lakes, has a heavier rainfall than Connecticut, and many lakes occur in arid regions.

How, then, are we to account for the presence of lakes, and bowlders, and soil resting on unaltered bed rock, and the unusual topography to which the scenery of Connecticut is due? The evidence is conclusive that these features owe their origin to the invasion of a glacier of continental

Fig. 18. Map showing Southern Limit of the North American Continental Glacier.

dimensions during the Glacial period — a glacier which occupied the area indicated on the map, Fig. 18. There is now practically unanimous agreement on this point among students of geology, but before the action of ice was thoroughly understood these features were a puzzle to layman and scientist alike.

HISTORICAL SKETCH.

In this connection it is interesting to note the various interpretations that have been given to these features of

New England, and the way in which the true explanation has been developed.

The *American Journal of Science* was established by Benjamin Silliman, at New Haven, in 1818, and is thus the oldest scientific journal in this country. An examination of its pages shows that the unusual features of Connecticut topography were recognized at a very early date. Among the greatest puzzles to the early scientists were the presence of huge bowlders on the tops of the highest hills, and the abundance of sands in ridges and plains, suggesting great water work under flood conditions. In the absence of better explanations, these were regarded as evidences of the great flood described in Genesis; and the water surging from the ocean and drowning the land was supposed to have carried these huge masses of rock and deposited the material promiscuously over the state. When the surface deposits were examined in detail, however, it was found that no such catastrophe could account for the features represented. Silliman early recognized the peculiar characteristics of our superficial deposits, as is shown by the following quotation: —"The almost universal existence of rolled pebbles, and boulders of rock, not only on the margin of the oceans, seas, lakes, and rivers; but their existence, often in enormous quantities, in situations quite removed from large waters; inland,—in high banks, imbedded in strata, or scattered, occasionally, in profusion, on the face of almost every region, and sometimes on the tops and declivities of mountains, as well as in the vallies between them; their entire difference, in many cases, from the rocks in the country where they lie — rounded masses and pebbles of primitive rocks being deposited in secondary and alluvial regions, and vice versa; these and a multitude of similar facts have ever struck us as being among the most interesting of geological occurrences, and as being very inadequately accounted for by existing theories."* At a later date Silliman published a letter signed "A," in which the following statements occur:—"There is one circumstance connected with the

* *Am. Journal of Science*, series 1, vol. III, p. 49, 1821.

earth's surface, which has not, that I am aware of, been noticed by any writer on Geology. The surface of every portion of the mass of rock, composing the nucleus of the earth, and which has not been exposed to the action of the atmosphere, is found worn quite smooth, and this equally, whether the covering of earth be shallow, or deep, of whatever species of rock the mass may consist, or however unequal and irregular may be the form which it has assumed. The common appearance of the surface is highly artificial, as if worn down by some powerful but not very delicate agent. The harder parts have in some instances, especially when forming veins in a softer stratum, the *feeling* of being polished, but the general character of the surface, although smooth to the eye, is somewhat rough to the touch, with slight grooves or channels, running in a uniform direction, very nearly north and south, but from a little west of north to a little east of south."*

These passages show Professor Silliman and his correspondent to have been field geologists of exceptional ability; and their observations and descriptions have been verified time and again. They nevertheless could conceive of no other explanation of the facts than the supposition of currents of water of tremendous strength, and they suggested most fantastic hypotheses as to the cause of such currents.

In the Geology of Connecticut by J. G. Percival (published in 1842), the surface deposits are classified as Diluvium and Alluvium — the former name being applied to the materials deposited by strong currents and "accumulated loosely and irregularly," and the latter to stratified materials deposited by quiet waters.

Certain features, however, were not satisfactorily explained. No currents of water, however powerful, could lift these great bowlders and leave them scattered in such helter-skelter fashion. Furthermore, the rocks, even on the highest hills, were seen to be scratched and highly polished in a way unlike those worn by water. The theory was sub-

***Am. Journal of Science*, series 1, vol. XI, p. 100, 1826. The writer was probably Nathan Appleton.

sequently advanced that, at the time of the Noachian deluge or at some other time, icebergs had been driven through New England, and that the bowlders present had been dropped from them. It is well known that icebergs have about seven-eighths of their volume submerged, and so may reach down far enough in shallow water to polish and scratch the rocks. That ice had taken some part in the grooving and polishing of rocks, was a growing idea during the second quarter of the nineteenth century. Mr. Peter Dobson, of Vernon, Connecticut, regarded it as an important factor in producing scratches and markings on rocks, as is shown by the following extract from a letter addressed to Professor Silliman, November 21, 1825:—"I think we cannot account for these appearances, unless we call in the aid of ice along with water, and that they [the bowlders described in the letter] have been worn by being suspended and carried in ice, over rocks and earth, under water."* It is remarkable that the first published suggestion of the agency of ice in the phenomena of the drift should come from one who was not a professional geologist, but a man of business. Professor Edward Hitchcock, although strongly impressed by the views which had already been promulgated by Louis Agassiz, still declared, in 1857, "I lean, therefore, at present, to that [hypothesis] which imputes most of the work on this continent to immense icebergs, ice-floes, and shore ice."† Still more recently the iceberg theory found a champion in Sir John William Dawson, who presented elaborate arguments in its favor as late as 1868;‡ but even the influence of so great a name could not retrieve a lost cause.

With the coming of Professor Agassiz to America, in 1846, a new era was opened in the study of the surface geology of New England. Agassiz was a Swiss, and was thoroughly acquainted with the movements of glaciers in the Alps and in other parts of Europe. As far back as 1837 he

* *Am. Journal of Science*, series 1, vol. X, p. 218.

† *Illustrations of Surface Geology*, p. 71 (*Smithsonian Contributions to Knowledge*, vol. IX).

‡ *Canadian Naturalist*, vol. III, pp. 33-44.

had announced the conclusion that the fine striæ engraven as with a diamond point on the rocks of the Jura Mountains could not have been produced by water, and that the Alpine glaciers must have extended formerly across the intervening valley. In 1840 he visited Britain, and, after demonstrating the identity of the surface phenomena in England and Switzerland, made the then startling announcement "that not only glaciers once existed in the British Islands, but that large sheets (*nappes*) of ice covered all the surface."* This was the real beginning of the study of ancient glaciation.

On coming to New England Agassiz was struck with the similarity between the deposits and the topography here and the surface features of Scotland and the Alps. Starting with this general observation, he found more and more surface forms that could be ascribed to glacial work, and finally announced his belief that the northern part of the United States had been overridden by separate glaciers or by one great ice sheet.

The glacier theory of Agassiz was advocated by Professor Dana in his presidential address before the American Association for the Advancement of Science, in 1855, and in his "Manual of Geology," the first edition of which was published in 1862. To his great influence, doubtless, the general adoption of the theory by American students of geology, in the course of the next few years, is largely due.

THE WORK OF EXISTING GLACIERS.

The proof of the theory of glaciation is found in the correspondence between the work attributed to the supposed ancient ice sheet and that known to be done by recent glaciers. The glaciers of the earth are to-day confined to high altitudes and high latitudes. A certain amount of cold is necessary for their existence; and their presence in or absence from a given locality depends upon the relation between the amount of precipitation and that of melting. As climates are now arranged, small glaciers exist about the

* *Proceedings of the Geological Society of London*, vol. III, p. 331, 1840.

high mountain groups of the world, and large ones near the poles.

If we take an individual glacier, as, for instance, one of those in the Alps or on Mt. Shasta, we find that it is an ice stream or mass of ice occupying the valley depression and reaching down somewhat below the snow-line. It is a tongue of ice, so to speak, extending a considerable distance beyond the region of perpetual snow. On top of the glaciers are commonly found masses of rock, large and small, which have fallen from the side cliffs and are carried with the ice as it moves slowly down the valley. Through the crevasses in the glacier these rocks may find their way to the bottom. If the lower end of this ice stream is examined, it will be seen that water is generally flowing from it, and that a mound or ridge or irregular mass of rock material is deposited at the end of the glacier.

In the lower course of the valley, where the ice formerly existed, and from which it has only recently retreated, it is further seen that the rock walls have been smoothed and scoured and scratched in a way very different from forms produced by water; also that masses of material are piled on the sides of the valley, and that the valley bottom is either bare, polished, and striated rock, or is covered over with a jumbled mass of bowlders, clay, etc., or is partly filled with sands and gravels left by the waters from the melting glacier. These deposits are very unlike those found in an ordinary river valley, and afford conclusive evidence that the work here is the result of a tongue of ice which has now receded farther up the valley.

When glaciers of much larger dimensions than the valley type are examined, as, for instance, the Malaspina Glacier of Alaska or the Greenland ice sheet, deposits of the same character are found, and the same effects are seen to have been produced on the underlying rock.

If, then, we find in certain parts of the world, far removed from existing glaciers, topographic forms and deposits which differ in no essential particular from those found in valleys now filled with ice streams, it is reasonable

to suppose that ice formerly occupied these places; and this hypothesis is strengthened in proportion as we find the details of erosion and deposition corresponding to details of work done by existing glaciers. Additional evidence is furnished by the fact that the other great dynamic forces — water, wind, and volcanoes — were never known to have produced results which are even approximately similar. It is on such grounds that the surface topography of Connecticut is ascribed to the work of a prehistoric ice sheet, and it will now be in order to explain somewhat in detail the effects of the work of this agency on the topography of the state.

Methods of Glacial Work.— As a geological force, ice works in a way peculiar to itself. It is not liquid enough to adjust itself to minor irregularities of the surface, but still is controlled by the larger irregularities. It is not sufficiently adjustable to erode a pit of a few feet or a few inches in diameter, as may be done by the chemical action of the atmosphere, yet it is adjustable enough to be modified by an uneven surface. The original topography of a given region is therefore effective in determining the amount of cutting into the rock below. The chief work of rivers in erosion is performed by the impact of the pebbles against the banks and bed of the stream; and up to a certain point a river is effective in its erosion in proportion to the amount of material that it carries in suspension and rolls along the bottom. Water is so mobile that it adjusts itself to all the minor inequalities in its path. Wind works by abrasion; it carries the finer particles suspended in the air and hurls them against projecting objects, but it carries only the finest of materials, and is too irregular in its direction and velocity to produce widespread uniform results.

Ice, in the form of glaciers, works in an entirely different way. The moving ice is effective in erosion because of its weight, and because of the imbedded rock fragments. In its grinding motion it is a ponderous plane, driven with practically resistless force over an uneven land surface.

The result is that it grinds down rock, both hard and soft, to a common level, and does not select the weaker or less resistant portions, as would a river or the wind. Its work is like that of a giant power-plane, which goes across knots and clear places in a board with equal effect. A mass of ice a thousand feet in thickness, such as was present over the locality of New Haven during Glacial time, exerts a pressure of 50,000 pounds per square foot. This enormous weight and the pressure which impelled it slowly forward produced the great erosion and rounding which are now so conspicuous features in the topography of Connecticut. A glacier is a coarse tool, yet at the same time a tool amply sufficient and admirably adjusted to perform all sorts of grinding and polishing.

As a transporting agent it is very unlike wind or water. Water can carry rock fragments of limited size, the weight of the largest fragments (if, for simplicity, we suppose the shape to be alike and the specific gravity equal) varying as the sixth power of the velocity. Glaciers carry large and small bowlders with equal ease. When materials are deposited by water, they fall in accordance with their size and specific gravity, and are therefore sorted and stratified; while a glacier deposits them in unassorted masses, regardless of their shape, size, or composition. In passing over a new land area the work of an ice stream would be first to scrape off all the soil that had been formed over the rock, and usually not only that, but to grind down into the rock itself to a greater or less distance. Hence, after the retreat of the ice, the soil which, under the action of the atmosphere, had been formed during long geological time, would have been removed, and that left on the ground would be entirely different in character from the rock below. This explains why the soil in Connecticut is commonly made of materials unlike those in the underlying ledges. For this reason, also, as a rule, sections in wells, cellars, and quarries in the state do not exhibit a gradual transition from surface soil through rotten rock to firmer and firmer rock, but show a clean-cut line between the cover and the bed underneath.

The soil rests directly upon fresh, unweathered surfaces, as shown in Plate XXV, Fig. 2.

The method of work of the water running from a glacier is exactly the same as that of other running water and requires no special explanation.

THE WORK OF THE GREAT GLACIER IN CONNECTICUT.

Glaciation.— The work of the ice sheet in general is included under the term glaciation, and exhibits two main phases; (1) the work done directly by the ice, and (2) that effected by water resulting from the melting of the ice. The work done directly by the ice is first of all shown in the appearance of the ledge or bed rock which has been overridden by the ice sheet. Under the influence of the atmosphere such a ledge would be covered by partially decomposed rock, and would show a dulled or weathered surface; but, when overridden by ice, the rock is worn smooth, and is scratched or polished.

Striæ.— Part of this smoothing and polishing is done by the ice itself because of its great weight and movement, but a much larger share is done by the bowlders and pebbles that are imbedded in the bottom of the ice sheet. These are shoved along over the ledges, and cut grooves or fine lines in proportion to their size. When the pebbles are very small they result in polishing the rock. Plate XXVII shows the polished and scratched rock surface on South Mountain, in Meriden. All the soil and decomposed material have been carried to the southwest by the glacier, and only a few foreign pebbles remain. The characteristic glacial striæ may be observed in Connecticut wherever ledges are exposed which have not weathered to any great extent. Resistant rocks of fine texture, such as the traps, granites, gneisses, and quartzites, are best adapted to retain scratches; but schists, limestones, sandstones, and even shales, retain records of the ice invasion. These grooves and scratches will of course be in the direction of the main ice movement, and will enable us to determine the course of the ancient ice sheet. On the accompanying map (Fig.

PLATE XXVII.

GLACIATED SURFACE, SHOWING GROOVES AND STRIÆ; SOUTH MOUNTAIN, MERIDEN.

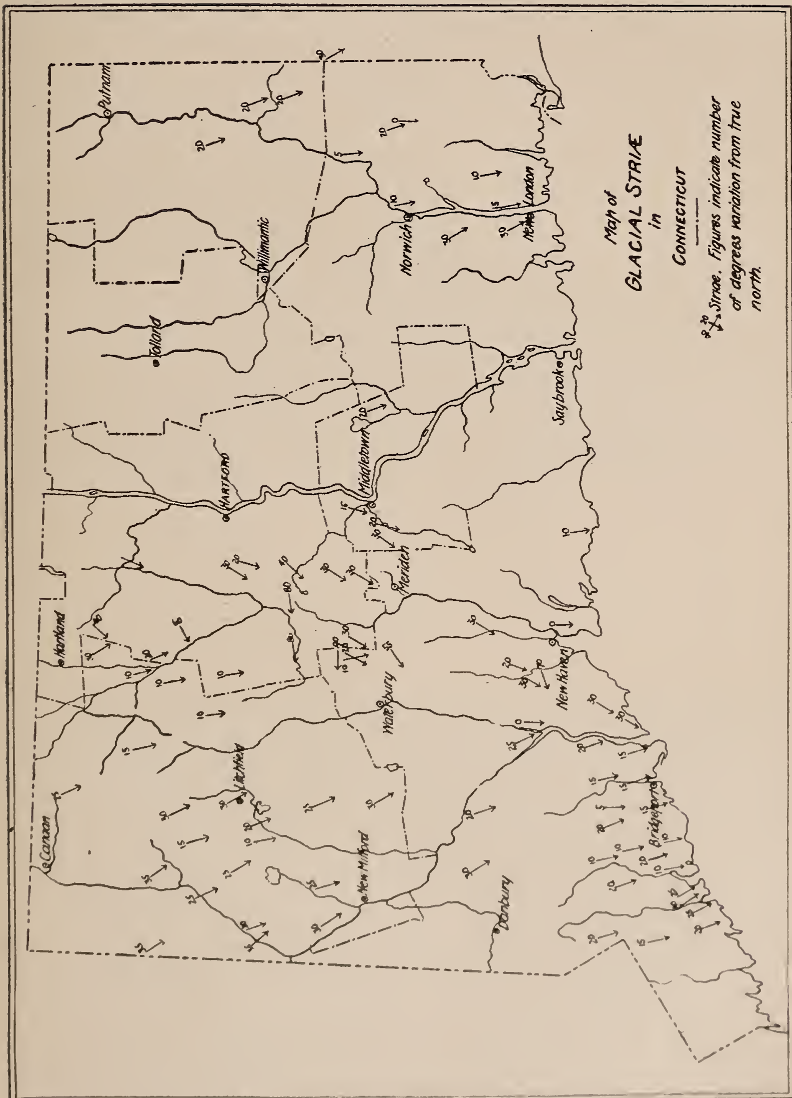

Map of
GLACIAL STRIÆ
in
CONNECTICUT
Striae. Figures indicate number of degrees variation from true north.
Putnam
Willimantic
Tolland
Norwich
New London
Saybrook
Hartford
Middletown
Meriden
Hartland
Waterbury
New Haven
Litchfield
Canaan
New Milford
Bridgeport
Danbury

Fig. 19.

19), the courses of a number of striæ are plotted, and it will be seen that the main movement of the ice over Connecticut was a little east of south, but that, where large valleys existed, the lower part of the glacier was controlled by them, and the variation in the direction of the striæ shows the changes induced by the topography.

Glacial Pebbles.— Not only are the rock ledges modified by the ice sheet, but the pebbles and bowlders held in the bottom of the ice will themselves take on characteristic forms. They are, as it were, chisels held on the lower side of a giant power-plane; while the board underneath the plane is smoothed off, the chisels are at the same time worn down. In this way the bowlders in the bottom of the ice are polished and grooved and striated along one or more faces, leaving other sides unaffected. Such pebbles are easily distinguished from pebbles worn by water, for in the later case the pebbles have been rolled against each other so that their corners and angles are entirely worn off, leaving them approximately spheroidal. Glacial pebbles are polished and flattened, but not rounded. If collections of water-worn and ice-worn pebbles are compared, these differences will at once be apparent, as shown in Plate XXVIII.

Bowlders.— Another evidence of ice work is the great abundance of bowlders strewn without order over the entire state. Many a e very small; those ranging in size from six inches to three feet in diameter are abundant; many are found five to ten feet in diameter; and certain ones occur which exceed twenty feet in their largest dimensions. The moderate-sized ones have been in many places picked off from the surface and built into numerous stone walls, the smaller ones still remaining in the fields, while the largest ones constitute prominent landmarks. It is noted, furthermore, that these bowlders lie in every conceivable position — on the tops of the highest hills, in the valleys, and on the hill slopes. They may rest on very large bases, or be nicely balanced on some small facet, apparently

PLATE XXVIII.

Fig. 1. GLACIATED PEBBLES—ANGULAR STONES SMOOTHED AND STRIATED; FAIR HAVEN.

Fig. 2. WATER WORN PEBBLES—ROUNDED. FAIR HAVEN

in an insecure position. Oftentimes the solid rock underneath is seen to be polished and grooved, and very frequently it happens that this rock is of an entirely different character from that which constitutes the bowlder. It will be readily seen that such a bowlder could not be the result of weathering of the ledge in place, but has been brought from some distance and deposited in its present position. These bowlders may often be traced back to their original ledge, and thus give evidence of the distance of transportation and the direction of ice movement. Sandstone bowlders from central Connecticut occur at Montville; dolomite bowlders from Canaan are found in Litchfield; and bowlders occur at New Haven which have traveled from the Berkshire Hills. They are far too heavy to have been carried by wind, and their weight and their shapes make it unreasonable to suppose that they could have been deposited by water. The simplest explanation to account for the character and distribution of bowlders is that they were imbedded in the ice in the interior or at the bottom of a glacier, or were riding on top of the ice sheet; and, as the ice melted, they dropped down and came to rest wherever and in whatever position they might be when released from the ice. These larger bowlders have often received local names, and have long excited interest. The Judges' Cave at New Haven is a typical specimen. Though now broken, it was originally doubtless one mass weighing about 1,000 tons, and was probably transported from some point north of Meriden.

Till.— When a glacier retreats in a mountain valley, it usually leaves at the front and at the sides masses of heaped-up deposits called moraines; in addition to these it also distributes material everywhere along the bottom of the valley. The latter material comes from the rock torn off from the glacier's bed, with the addition of fragments from the top of the ice. In general the deposit on the floor of the valley is hard packed, and contains pebbles of various sizes and in all sorts of positions, with the clay and sand made

from finely ground matter (see Plate XXIX, Fig. 1). All the rock débris which accumulates underneath the ice is called the ground moraine. In the case of the continental ice sheet, part of which occupied New England, the margin extended through Long Island; and the great mass of material reaching from Brooklyn eastward and forming the "back-bone" of the island, is a terminal moraine, indicating the position of extreme advance of this gigantic glacier. Throughout the state of Connecticut the ground moraine was deposited; and, because of its method of deposition, the material composing it is a compacted mass of unassorted and unstratified bowlders, pebbles, and clay, which have been pressed down by the great weight of the ice above. This deposit is the *till,* or "hard-pan," as it is popularly called. Its bowlders are those which are met with in fields, and which are uncovered in sinking wells, particularly on the higher lands. The hard-pan, or till, is deposited very generally over the state, and has been jammed against the hills and spread over the highlands in such a way as to reduce many minor inequalities in the land surface. From a study of the well sections in the state it is seen that the till varies in thickness from a few inches where the topography was such as to allow even distribution, to over one hundred feet where the ice has crowded its ground moraine against some valley side.

Drumlins.— Over an even land surface an ice sheet of uniform thickness would spread the till fairly regularly; but, if for any reason the amount of ice is decreased, or the original topography is such that it is difficult for the ice to carry all the material in the ground moraine, it may pile it up in heaps and override it, just as rivers deposit sand bars along their beds when they are unable to carry all the material furnished by their tributaries. These mounds of till are called *drumlins.* They are elliptical hills, elongated in the direction of the ice movement, and in Connecticut are generally a quarter of a mile or more in length, and rise forty to one hundred feet in height above their bases. They have remarkably smooth convex outlines, quite unlike the ordi-

PLATE XXIX.

FIG. 1. TILL, NEAR YALE FIELD, NEW HAVEN.

FIG. 2. STRATIFIED DRIFT NEAR YALE FIELD, NEW HAVEN.

The hat in the picture shows size of pebbles.

Photograph by Freeman Ward.

PLATE XXX.

DRUMLIN, NEAR HIGHLAND PARK, MANCHESTER.
Photograph by H. H. Robinson.

nary hummocky deposits of a moraine. When occurring in groups they constitute prominent topographic features, and rise above the general surface much like rock ridges, but with the characteristic drumlin form. The hills about Pomfret are of this character, as are also those within the city of New Britain; Buckwheat Hill in Meriden is also of this type, and many more are scattered over the state. Plate XXX shows a typical Connecticut drumlin. Rock ridges and sand deposits sometimes imitate the forms of drumlins, but close examination reveals the difference. Drumlins have no bed rock exposed, and no stratified sands or gravels enter into their composition. They are entirely of till; and this fact, together with their form, serves to distinguish them from other topographic features.

Composition of Till.— The composition of till is well shown by analyses of sixteen samples taken from drumlins by Professor Crosby.* All the stones over two inches in diameter, amounting to from 8 to 10 per cent. of the whole bulk (rarely 20 per cent.), were taken out. The finer parts remaining were analyzed mechanically, and found to have the following composition:—

Gravel	Coarse	17.08	24.90
	Medium	2.99	
	Fine	4.83	
Sand	Coarse	3.33	19.51
	Medium	9.25	
	Fine	6.93	
Rock flour	Coarse	12.80	43.76
	Medium	6.52	
	Fine	24.14	
	Superfine	0.30	
Clay	First size	0.86	11.77
	Second size	9.13	
	Third size	1.78	
			99.94

* *Proceedings of Boston Soc. Natural History*, vol. XXV, p. 123.

[The material classed as clay is a soft impalpable mass coming from the mechanical disintegration of argillaceous rocks or from the chemical decomposition of other rocks. Rock flour is mechanically formed, and is mostly fine quartz, and always feels gritty.]

Stratified Drift.— The stream which issues from the snout of a glacier is always heavily laden with pulverized rock. This material is carried for some distance, and is finally deposited where the stream, because of decreased velocity, is no longer able to carry the load. In the same way, water produced by the melting of the continental ice sheet has deposited material over all of the lower lands in Connecticut. It will be readily understood that deposits formed in this manner differ in no important particular from those made by ordinary rivers when at flood stage; the only difference being that rivers are supplied by the rainfall, and the materials borne along come from rock decomposed by the action of the atmosphere, whereas, in the case of glacial streams, the water comes from the melting of the ice, and the material carried is that previously ground up by the ice mass. Because the ordinary river carries material which was taken from the surface of the earth and which had been greatly weathered and oxidized where exposed to the atmosphere, the muddiness of rivers is yellowish in color; whereas the glacial streams, carrying freshly ground rock, are more apt to present a milky appearance. Deposits made by glacial waters consist of ground-up fragments of whatever rock was acted upon by the glacier, and accordingly show great variety in composition.

The variations in the velocity of glacial rivers resulted in the deposit of materials of different grades of fineness. When streams were at flood stage, pebbles from one inch to six or eight inches in diameter, or even larger, could be transported; in more quiet water only the finest sediment could be borne along. Therefore glacial deposits made by water are everywhere in layers, or stratified; materials of different sizes or different specific gravities form distinct beds. For this reason the general name *stratified drift* is

given to this class of deposits. Such water-laid drift may be readily distinguished from till by the fact that it is sorted and stratified, and does not contain bowlders of large size, whereas till is an unsorted, jumbled mass, variable in texture and composition, and containing fragments of all sizes up to the largest known bowlders. The contrast between the two types of deposit is shown in Plate XXIX.

Sand Plains.— When the waters from the melting ice were not confined to definite channels or valleys, they spread widely over the country, depositing the material in the form of a plain. Such plains may have been above sea level, or may have been deltas slightly below sea level. The streams wandered back and forth on these plains, varying in velocity and in quantity, but with the result that the original topography was completely buried in a fairly even stretch of sands and gravels. Such a sand plain exists in the region about Wallingford. Where bodies of quiet water were present, and streams from the melting ice entered them, the coarse material would be dropped near the shore, and only the finest particles could be held in suspension long enough to be carried far out and deposited on the bottom of the lake. When the waters drained away, such areas would form clay beds. Deposits of this nature are believed to constitute the clays of Berlin, North Haven, Milldale, and other localities in Connecticut. Plains formed by glacial streams and lakes are common features, and may cover but a few acres, or may extend over many square miles, as the plains about Plainville and Plainfield.

Kames.— Near the edge of the melting ice sheet, just in front of and under the ice, the deposition of material would be extremely irregular. The free movement of the water would be obstructed by morainal material and by the broken masses of ice, so that, instead of flowing with a regular current, it would gush out with considerable force in certain places, while it would be ponded back at other places. Blocks of ice would remain detached, partly surrounded with sand or gravel, and considerable material

would be deposited by the water underneath the ice. The resulting topographic form would be a series of mounds and short interlocking ridges with hollows, the depressions being either dry or filled with water. Such mounds and ridges are called *kames*, and indicate a temporary halt in the retreat of the ice-sheet. These kame areas are generally confined to valley districts, or to the sides of ridges where the water emerged from the ice. In the Nepaug Valley, west of Collinsville, kames are well developed (see Plate XXXI, Fig. 1); also west of Cheshire, and in Glastonbury, Avon, and many other towns.

Eskers.— Streams running underneath the ice for any great distance, and fed by the melting ice itself or by water dropping down through the crevasses in the glacier, would make for themselves definite subglacial channels. They would meander after the manner of an ordinary surface stream, and would deepen their channels or deposit material in accordance with their velocity and load of detritus. If such a subglacial stream should deposit considerable material on its valley floor, the result would be an accumulation of sand and gravel, along a sinuous line, held up by the ice on both sides. When the glacier finally melted, the sand and gravel which had been deposited would be left as a ridge, marking the course of the subglacial stream. Ridges of stratified drift formed in this manner are called *eskers*, and serve to determine the direction of subglacial drainage. They are long, winding ridges of sand and gravel, rising to a height of from ten to thirty feet or more, and are usually sharp-crested, and often as regular as an artificial embankment. Eskers would naturally not form under the main part of the ice, but rather toward the extremity of the ice sheet; and the establishment of such definite channels implies the maintenance of one position for a considerable period of time. Eskers, therefore, like kames, mark a position where the glacier made a halt in its retreat. They are well developed in Connecticut, in Hartland, in Burlington, and elsewhere. Plate XXXI, Fig. 2, shows the esker

PLATE XXXI.

FIG. 1. KAMES, NEPAUG VALLEY.

FIG. 2. ESKER, EAST HARTLAND.

at East Hartland. It has a length of about a mile, and rises above the general level about thirty feet. A common feature of eskers is a swamp or lake on one side or both. Compounce Pond owes its existence to an esker which forms a ridge on the east and southeast. These long, winding ridges of sand and gravel are not confined to valley regions, but may occur on high land, and they cross the hills and valleys without regard to the present topography, in a manner that would be impossible for any surface stream.

While it is believed that eskers have been most commonly formed by subglacial streams, as described above, it is probable that some eskers owe their existence to streams flowing on top of the ice mass.

Kettle-holes.— The front of a melting ice sheet would not recede uniformly, but would present a great complexity of lobes and indentations, large and small. From time to time blocks of ice would become detached from the main mass, and might remain grounded or be floated for a time as icebergs. Such ice blocks might be entirely or partly covered with drift deposited by the streams from the melting ice. The block might remain thus partially concealed for a considerable time; but, after a while, it would melt, and the sand and gravel slump down on all sides to occupy its place, forming a conical depression. Such depressions are called *kettle-holes,* and occur usually on sand plains formerly covered by widespread streams at flood stage. They give the plain a pitted appearance. The New Haven sand plain is thus marked, particularly about Pine Rock and Mill Rock.

Lakes.— One of the characteristic features of Connecticut topography, as compared with that of the states farther south and west, for example, Tennessee or Kentucky, is the great abundance of lakes, swamps, and ponds. The Connecticut Topographic Atlas shows 1,026 lakes and 420 swamps.* There are of course many others too small to be

* In counting these lakes the larger artificial ponds are included. Most of these were originally lakes or swamps, and the dams have only increased the area of the water body. The number of basins made entirely by man is probably more than offset by the number of water bodies drained since the first settlement of Connecticut.

mapped. These lakes owe their existence chiefly to the fact that Connecticut was in the path of the continental glacier.

Lakes are temporary features of a landscape, and can exist only where the land has been recently raised from the sea or modified by some widely acting agent. Rivers tend to destroy lakes both by filling in at the upper end and by cutting down the outlet. Furthermore, vegetation works into lakes from all sides, converting them first into swamps, then into bogs, which finally become grassy plains, whose history is revealed by the thick deposits of peat beneath the surface. It is only because the surface of Connecticut has been lately modified that such an abundance of water bodies exists. When the glacier came down across New England from the north, it plowed off the loose material from hill and valley alike, cutting deeply in some places, filling up other places, thus changing extensively the details of the preexisting topography. When the glacier retreated, it left material spread irregularly over the entire district. Till and stratified drift, in the form of ground moraine, terminal moraines, kames, eskers, and sand plains, were left behind in such a manner as completely to remodel the landscape. Valleys were filled, elevations of different types were made, and in places rugged land forms were converted into plains of till or stratified drift. Rain falling on such a surface did not find stream channels already established to carry it to the sea, but found disconnected depressions of various shapes and sizes. The hollows, accordingly, were filled with water; and ponds and lakes must abound until the streams can be reestablished and a system of ramifying tributaries developed to drain the land. Sufficient time has elapsed since the Glacial age for many streams to be reestablished on the modified surface; but, while numerous lakes and ponds have been drained, hundreds of them still remain as abnormal parts of drainage systems.

Most of the lakes of Connecticut occupy depressions made by the deposition of glacial material, but some lakes

are contained in rock basins, and owe their existence to the action of ice in eroding the rock. For example, Lake Saltonstall at New Haven does not seem to be due to the obstruction of the former drainage system, but to have been eroded by the ice from shales overlying a lava flow. It is separated from the waters of Long Island Sound by only a few feet; it has an extreme depth of 108 feet, its bottom being more than 82 feet below the level of the sea, whose tides rise and fall at its very edge. The water is fresh, and is used for the New Haven water supply.

Swamps.— Lakes and swamps are to be considered as members of one family, and to differ only in age. Originally they were all lakes with no vegetation surrounding them. The material forming their shores was either rock or glacial débris. If rock, many years must have elapsed before it became sufficiently decomposed to form soil; if till or stratified drift composed the lake border, the material was already sufficiently broken up to give access to roots. In either case considerable time must have elapsed after the final retreat of the glacier before vegetation to any extent took possession of the lake shores. The first plants to appear were lichens and mosses. Certain mosses, particularly those of the genus *Sphagnum*, have a habit of growing out on the water surface and forming a mat of intertwined stems connected with the shore. At this stage the lake is an open water body with a border of vegetation floating near the rim. Gradually this rim of moss creeps toward the center of the pond until finally it is completely closed in and covered over with a layer of vegetation. The lake is now a swamp; and such a swamp, with a floating layer of aquatic plants, is known as a "quaking bog"; it is possible in some cases to walk across the old lake on a mat of vegetation while the water remains below. These mosses have a habit of growing at the top while the old stems are dying below, and the rotted fragments drop to the bottom of the pond and help to fill it up. This decayed vegetable matter is swamp muck, and may accumulate until the pond is completely filled and

becomes a bog of peat. The peat remains saturated with water for a very long time, and usually until the bog is artificially drained. Speaking in geological terms, these peat bogs are the beginnings of coal beds. As soon as the moss and similar species have made some headway over the water surface, many other forms of plants come in to take possession. Sedges, grasses, and other herbaceous plants crowd out from the shore line. Alders, willows, white cedars, and other water-loving shrubs follow. The work of vegetation is greatly aided by rain and running water, which bring down material from the higher ground and deposit it along the borders of growing swamps. When drained, these peat bogs may be converted into rich agricultural lands, and they contain at the same time a very extensive supply of peat, which is available as fuel.

Thus it is seen that there is every gradation between lakes with shores of rock or glacial drift, and swamps partly or entirely clogged by vegetation. At the close of the Glacial period there were probably 4,000 lakes within the state of Connecticut, which owed their origin to the ice invasion; 1,026 remain somewhat as originally formed; 420 are much choked with vegetation, and are represented on the map as swamps and bogs. The other 2,500 have been drained by the natural development of stream tributaries, or filled with débris from the sides, or completely conquered by aquatic plants. They now exist as plains of small extent and form choice garden spots.

Modified Drainage.— Before the advent of the ice sheet the rivers of Connecticut took a general course to the south and southeast, in accordance with the slope of the plain produced by an uplift near the close of Cretaceous time (see page 29). Some of these streams seem to have been controlled in their direction by the structure of the rocks underneath, as has been indicated by Professor Hobbs.* The presence of the ice sheet altered the surface of Connecticut to such an extent that many of the rivers no longer

* *The River System of Connecticut* (*Journal of Geology*, vol. IX, p. 469).

run in their original channels, but have taken new courses and show modifications which are not part of a stream's normal development.

When a river system has opportunity to develop on a land surface, unaffected by accidents, the tributaries slope in the same general direction as the main stream, and enter the main stream at acute angles. They do not normally run parallel with the main stream, nor in a direction opposite to that of the main stream. Furthermore, under normal conditions, the tributaries of a stream have the same slope as the main stream, or a steeper slope, and meet the main stream at grade.

If we look at a map of Connecticut, we shall find that there are many streams which do not have these normal characteristics; there are tributaries running up stream, so to speak, and tributaries which have practically no slope, and still others which meet the main stream, not at grade, but by coming over a waterfall. Many streams, moreover, have apparently been cut in two, and drain in opposite directions, although their common valley continues as before. Some stream valleys have lakes along their course, which again is an abnormal feature in stream development. To make these points clear it may be well to describe a particular river system and to show the changes which have taken place because of the presence of a great ice sheet.

The Farmington River.— The Farmington River (see Fig. 22) rises in Massachusetts to the north of Otis, and flows southeast for a distance of about thirty miles to Farmington. It there turns abruptly north to Tariffville, a distance of fourteen miles; finally bending to the east and southeast to enter the Connecticut River at Windsor. It receives many tributaries from the north, and certain large streams from the south and west. By an examination of the glacial deposits and the ancient valleys and the general structure of the region, we find that the Farmington has been very greatly modified, and that the course that it now holds is entirely abnormal. In pre-Glacial time this river

Fig. 20. Supposed Pre-Glacial Drainage of the Farmington-Quinnipiac Valley.

Fig. 21. Supposed Drainage of the Farmington-Quinnipiac Valley at the close of the Glacial Period.

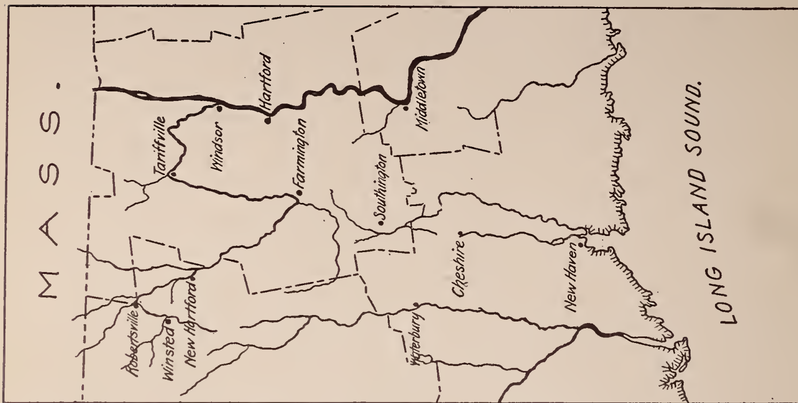


Fig. 22. Present Drainage of the Farmington-Quinnipiac Valley.

flowed from the vicinity of Congamuck Ponds directly south through Farmington, Plainville, Southington, and Cheshire, and entered the Sound at New Haven, as shown in Fig. 20.* The main tributaries from the west were the upper Farmington, which came down from Massachusetts through Colebrook, Barkhamsted, and New Hartford, and the Pequabuck, which came through Bristol. During the Glacial epoch, the entire river system was buried beneath the ice. As the ice sheet retreated, it left deposits of material at different places along the Farmington and its branches, which dammed the stream, and formed a number of lakes, interrupting the continuity of the river system (see Fig. 21). A lake was formed at Pine Meadow; the stream below that point was blocked, and found a new course for itself through the gorge at Satan's Kingdom. The pre-Glacial Farmington River was dammed at Cheshire, and was forced to give up its course to New Haven. It turned accordingly to the east, and carved the gorge of the Quinnipiac through a sandstone ridge at South Meriden. Another dam was built in the region of Southington, and a lake was formed extending through Plainville, Farmington, and Avon. The lowest place in the rim of this lake was at Tariffville, and the stream was forced to take that roundabout way to the Connecticut River. Mill River and Quinnipiac River represent portions of the pre-Glacial Farmington, and the Northampton Division of the New York, New Haven, & Hartford Railroad, which is built along the line of an old canal, runs for a large part of its course along the channel of the ancient river.

In the vicinity of Winsted the arrangement of tributaries to the upper Farmington, in Glacial and pre-Glacial times, was very different from the present. Mohawk Brook, which is now a small stream entering the Farmington near Pleasant Valley, has passed through several stages. At one time, previous to the Glacial period, Mohawk Brook and Mad River at Winsted were parts of the same stream, and drained

* For a discussion of probable drainage conditions at a still earlier period see page 220.

a considerable area from Norfolk eastward. Later the Naugatuck River worked up through Winsted, and captured the western (upper) part of this stream, so that Mad River became a tributary to the Naugatuck, and reached the Sound by way of the Housatonic. The advent of the ice sheet modified this drainage considerably; a dam was built in the Naugatuck Valley, south of Burrville, by material left by the glacier, and similar deposits in East Winsted served to close up the channel through the Mohawk to the east. These two dams formed a lake which extended over the present site of Winsted, from Robertsville to Burrville, into which Mad River drained from the west. These glacial dams were built so high that the lowest part of this newly made lake basin was at the north, and the lake overflowed into Sandy Brook, thence into the Farmington, near Riverton. The stream which wanders along the floor of the extinct lake is significantly called Still River. The falls at Robertsville date from the time of the ancient lake, and have since been cutting a gorge back from Sandy Brook toward Winsted. The changes above described, subsequent to the capture of Mad River by the Naugatuck, are shown in Figs. 21 and 22.

Still River at New Milford is another illustration of the modification of drainage by the ice sheet. This river runs north in a direction opposite to that of the Housatonic, to which it is a tributary. Many similar instances within the state might be pointed out.

Waterfalls.— If a river system is allowed to develop normally, unhindered by accidents, it continually cuts its channel deeper, until its profile from source to mouth is reduced to a smooth and gentle curve, concave upward, called a profile of equilibrium. That curve, at its lower extremity, coincides with the sea level, which is the general base-level to which rivers are working. Its tributaries likewise cut their profiles to profiles of equilibrium, the base-level of each tributary being the level of the main stream at the mouth of the tributary. When that condition is reached,

the entire river system is said to be graded, and rapids and waterfalls are practically unknown. When, however, a dam is formed in a stream, either artificially or by a glacier, waterfalls may be produced, which, as they are cut back, may be converted into rapids. The same thing happens when a valley is filled and the stream is forced to make a new way for itself across the country, until it drops again into its former channel or into the valley of another stream. Waterfalls are common in Connecticut, and practically all of them are due to the fact that the pre-Glacial drainage system has been greatly modified, and the course of rivers changed by the deposits from the ice sheet.

ECONOMIC RELATIONS OF GLACIAL DEPOSITS.

Soils.— Connecticut soils are practically all glacial. The material composing them has been carried for some distance from the north, usually but eight or ten miles from its source, but some of the material has come from Massachusetts, from Vermont, or even farther north. It is therefore *transported soil,* in contrast with the local soils in the southern states, which come from the decomposition of rock in place. Because of its origin the soil contains fragments of rock of all sorts — igneous, sedimentary, and metamorphic — and of all shapes and sizes. A great variety of soil is therefore found within a limited area, and adjoining fields may differ markedly in their agricultural value because of different soil constituents and textures.

Rocks thinly covered by till, and areas where coarse till predominates, are occupied by forests. Either they have never been cultivated or they have been abandoned. Where the bowlders are not too numerous, such areas are suitable for pasture and hay lands; but the soils are cold, retain water too long, and are apt to form bogs. The finer till, especially when the bowlders have been picked off, makes good agricultural land. Mechanical analyses of such soils by the United States Bureau of Soils are given in the following table, the large bowlders having been removed in each case :—

Diameter in Millimeters.	Conventional Names.	Bloomfield.	Enfield.	Hazardville.
2 to 1	Gravel	2	12.45	5.26
1 to 0.5	Coarse sand	3.35	11.86	8.66
0.5 to .25	Medium sand	8.60	13.98	18.83
.25 to .1	Fine sand	31.25	14.78	21.00
.1 to .05	Very fine sand	34.22	17.51	18.83
.05 to .01	Silt	4.35	8.20	8.70
.01 to .005	Fine silt	6.20	8.67	5.30
.005 to .0001	Clay	6.57	10.23	10.87
	Loss at 110° C.	1.36	1.04	1.01
	Loss on ignition	2.03	1.69	1.77
		99.93	100.41	100.23

Stratified drift is more readily cultivated than till, and is the soil used largely for tobacco and field crops in general. This assorted glacial material forms a soil which usually lacks richness, but is warm, easily tilled, holds much water, and is readily occupied by roots. Stratified drift is relatively fine in texture, as will be seen by the following analysis of soil from various places along the Connecticut River:—

Diameter in Millimeters.	Conventional Names.	Windsor.	East Longmeadow.	Burnside.	South Windsor.	Burnham.
2 to 1	Gravel	2.20	0.00	2.23	Trace	4.11
1 to 0.5	Coarse sand	7.51	.31	7.73	6.84	11.83
0.5 to .25	Medium	33.50	2.84	25.25	42.86	29.20
.25 to .1	Fine	32.05	63.10	29.00	33.00	24.45
.1 to .05	Very fine	13.50	29.15	25.40	7.73	12.72
.05 to .01	Silt	4.47	1.15	3.45	2.63	3.48
.01 to .005	Fine silt	1.75	.96	2.10	1.70	3.28
.005 to .0001	Clay	2.78	1.42	3.22	3.50	5.20
	Loss at 110° C.	.80	.50	.77	.75	2.95
	Loss on ignition	1.30	.90	1.27	1.54	2.81
		99.86	100.33	100.42	100.55	100.03

Clays.— The clays of central Connecticut are of glacial origin, and occur as parts of the till and as strata on the

floor of abandoned glacial lakes. The lake clays are by far the easiest to work, and are the only ones used. They occur in broad basin-like valleys along the Connecticut River and its tributaries, and are very similar in structure and composition. The clays are worked at Hartford, Windsor, South Windsor, Berlin, Middletown, Milldale, and North Haven. The Hartford clay forms the largest deposit, and extends up the Connecticut River into Massachusetts, with a width of from three to five miles. The thickness of the deposit varies considerably. At Parkville and West Hartford the depth varies from sixty to one hundred feet; at Windsor it is only from eighteen to forty feet. The northern part of the deposit is interrupted by rock ridges and drumlins, but clay over twenty feet deep extends as far as Thompsonville. The Berlin-Middletown deposit occupies a narrow, flat area along the Sebethe River, and averages thirty feet in thickness. The color of the clay is always reddish brown, thus differing entirely from the bluish gray clay of the Hartford region. Chemically the clays are very impure, only one-third or less being kaolin. The remainder is composed partly of fine quartz grains, with some feldspar, and numerous flakes of mica. The percentage of iron is sufficient to secure a deep red color to thoroughly burned clay. The clays of Connecticut are used almost exclusively for the making of common brick. The yards are clustered at several points from Thompsonville to North Haven. A report on the clay beds and their economic importance has been prepared by G. F. Loughlin.*

Water Supply.—The fact that the entire state of Connecticut has been overridden by the ice has greatly affected its water supply. The numerous lakes and swamps and many of the small streams owe their position and their very existence to the continental ice sheet. Of special economic value are the hundreds of lakes which constitute the principal water supply of cities and villages. Furthermore, the fact that the soil of Connecticut is of glacial origin de-

* This report is published as Bulletin No. 4 of this Survey

termines its character as a reservoir for ground water. Wells sunk in the till are usually shallow, rarely over fifty feet in depth; and it is the practice to dig them but a few feet below the first prominent water horizon. Seventeen wells have been reported as being less than ten feet in depth, and yet they contained an abundant supply of water. In general the wells of till areas contain soft water, which varies in amount with the seasons. During an unusually dry summer, wells in the till in some sections of the state completely fail. The springs of the till-covered portion of the state for the most part afford soft water; and, like the wells, show their connection with the rainfall by their variation from year to year, and from season to season. Except in extraordinary seasons, however, the variation is slight, because in general the Connecticut rainfall is evenly distributed throughout the year.*

The stratified drift occupies a large part of the Central Lowlands of Connecticut, and also the valleys in the crystallines. It varies in depth from a few inches to over five hundred feet, and because of its prevailingly loose texture it forms a water reservoir of great capacity. Along sand plains, and in general throughout the Triassic area of Connecticut, water maintains a permanent level twenty to thirty feet below the surface; and the practice is to sink the wells some feet below this horizon, so that a reserve supply is always on hand. Where large quantities of water are required for manufacturing, swimming-pools, etc., several wells are sunk in close proximity, and connected with a single pump. Yale University uses twenty-four such wells to supply water for the gymnasium. Wells in stratified drift for the most part furnish an inexhaustible supply of pure water. Springs in the stratified drift are numerous, and vary in size according to the thickness and position of the sandy and clayey layers. Many are merely places where

* The rain-fall at New Haven is —

Spring,	11.13	inches.
Summer,	11.63	"
Autumn,	11.20	"
Winter,	10.93	"
Total,	44.89	"

the ground is wet from seepage; others furnish a sufficient supply for the farmhouse; and a few, like the Pequabuck Spring, near Bristol, afford water enough to form a brook.

Road Materials.— The best Macadam roads are made from the crushed rock quarried in the lava beds of the Triassic area of Connecticut; but good and much less expensive roads are made from glacial materials. The gravels and coarse sands of the stratified drift are spread so widely over the state that in general there is an abundant supply of these materials for road dressing. Till itself is not suitable for road-metal; but the bowlders which it contains furnish an abundant supply of suitable rock, and are conveniently located for crushing.

INDEX

CATALOGUE SLIPS.

Connecticut. State geological and natural history survey.

Bulletin no. 6. Manual of the geology of Connecticut. By W. N. Rice and H. E. Gregory. Hartford, 1906.

273 pp., 31 pls., 22 figs. (10 maps), 23^{cm}.

Rice, William North, and ***Gregory, Herbert Ernest.***

Manual of the geology of Connecticut. By William North Rice and Herbert Ernest Gregory. Hartford, 1906.

273 pp., 31 pls., 22 figs. (10 maps), 23^{cm}.

(Bulletin no. 6, Connecticut geological and natural history survey.)

CATALOGUE SLIPS.

Gregory, Herbert Ernest, and ***Rice, William North.***

Manual of the geology of Connecticut. By William North Rice and Herbert Ernest Gregory. Hartford, 1906.

273 pp., 31 pls., 22 figs. (10 maps), 23^{cm}.

(Bulletin no. 6, Connecticut geological and natural history survey.)

Geology.

Rice, W. N., and Gregory, H. E. Manual of the geology of Connecticut. Hartford, 1906.

273 pp., 31 pls., 22 figs. (10 maps), 23^{cm}.

(Bulletin no. 6, Connecticut geological and natural history survey.)